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COST ESTIMATION FOR SURFACE NAVY INVESTMENT IN ARCTIC-CAPABLE PLATFORM TO MAINTAIN NATIONAL SECURITY INTERESTS

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December 2014

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13. ABSTRACT (maximum 200 words)

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The United States is at a pivotal point with respect to its role in securing its interests in the Arctic. The Arctic is rapidly transforming from a relatively isolated region to one of increased human access due to receding ice. The changes that will take place in the Arctic region, and the challenges and opportunities these changes will bring, demand greater attention from the United States and its partners around the world.

After conducting a hybrid cost estimate, combining a parametric analysis of foreign Arctic surface vessels with an analogy approach based on the Arleigh Burke-class destroyer, the United States Navy could acquire an Arctic surface vessel costing approximately $1.5 billion, roughly $300 million less than the current Arleigh Burke design.

We recommend that the United States start building Arctic-capable surface vessels as soon as fiscally possible. Realistically, the United States should pair Arctic surface vessels with a more robust air, sub-surface, and unconventional warfare capability in the future to make the U.S. a more prepared Arctic nation.

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LIST OF ACRONYMS AND ABBREVIATIONS

AESG	Arctic Executive Steering Group
A/OPS	Arctic/Offshore Patrol Ship
CBO	Congressional Budget Office
CGC	Coast Guard Cutter
CNO	Chief of Naval Operations
CPOS	Center for Polar and Oceanic Studies
DDG/A	Arctic-capable Destroyer Concept
DSCA	Defense Support of Civil Authorities
DOD	Department of Defense
EEZ	Exclusive Economic Zone
EU	European Union
GAO	Government Accountability Office
HADR	Humanitarian Assistance Disaster Relief
HSPD	Homeland Security Presidential Directive
IACS	International Association of Classification Societies
IRR	Internal Rate of Return
ISA	International Seabed Authority
MDA	Maritime Domain Awareness
MSO	Maritime Security Operations
MUOS	Mobile User Objective System
NBC	Nuclear, Biological, and Chemical
NCCA	Naval Center for Cost Analysis
NORTHCOM	United States Northern Command
NSPD	National Security Presidential Directive
NPV	Net Present Value
NSR	Northern Sea Route
NWP	Northwest Passage
OPV	Offshore Patrol Vessel
OUSD(P)	Office of the Under Secretary of Defense (Policy)
PACOM	Pacific Command

PC	Polar Class
R&D	Research and Development
SAR	Search and Rescue
SAREX	Search and Rescue Exercise
SECDEF	Secretary of Defense
SOF	Special Operation Forces
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USN	United States Navy

EXECUTIVE SUMMARY

Studies have shown that Arctic polar ice has considerably decreased, both in extent and thickness, over the past 30 years (Boeing Phantom Works, 2011). As the ice continues to diminish in the Arctic, maritime traffic will considerably increase and international tension could rise due to contention over natural resource distribution and territory boundaries.

Strategic guidance at the National, Department of Defense, and Department of the Navy levels have clearly stated their priorities and strategic objectives in the Arctic region (United States White House, 2013; DOD, 2013a; CNO, 2014). Possible Russian military expansionism by 2025 in conjunction with indications of a Russo-Sino partnership in the region substantiates the need for increased U.S. involvement in the Arctic to protect its national interests and defend the homeland (Kline, 2014; OUSD(P), 2011; International Studies on the Polar Region, 2014). To align with these priorities and provide an Arctic-capable surface vessel cost estimate for the Surface Navy, we focused on three key mission-sets. These mission-sets include missile defense and early warning, deployment of sea and air systems for strategic sealift, and maritime security operations.

A cost estimate was conducted for an Arctic-capable platform concept based upon the United States' political and strategic priorities, the region's current geopolitical situation, and a possible future Arctic environment (Nussbaum, 2014). Capitalizing on the benefits of the current Arleigh Burke-class destroyer, our concept design, referred to as DDG/A, involves a complete hull-redesign including the strengthening of the hull, an engineering plant reconfiguration and removal of the hull-mounted SONAR system. The cost estimate exploited a hybrid approach incorporating a parametric analysis on like foreign Arctic-capable surface vessels and an analogous comparison to the Arleigh Burke-class destroyer (Nussbaum, 2014).

Based on our hybrid parametric and analogy cost estimate approach, we concluded that cost savings could be realized utilizing the DDG/A concept design based on the current Arleigh Burke-class destroyer. Our analysis concluded that the first

DDG/A would cost approximately $1.507 billion compared to the current Arleigh Burke destroyer costing approximately $1.8 billion/unit. With the admission that the United States may not need an Arctic-capable ship as robust as the DDG/A concept, various Arctic surface platform costs may be derived using this model as engineering details solidify.

Utilizing learning curve analysis, our model concluded a three-ship DDG/A fleet would cost, in FY15 dollars, between $3.95 and $4.33 billion; a five-ship fleet would cost between $6.70 and $7.03 billion; and a ten-ship fleet would cost between $10.72 and $13.49 billion.

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I. INTRODUCTION

While the Arctic continues to be a region marked with cooperation between nation states and generally free of significant conflict, we believe that the Surface Navy is lagging behind the power curve in its ability to operate and succeed in the Arctic if tasked. Many of the other Arctic Nations, as well as other non-Arctic nations like China, are preparing their Arctic capabilities ranging from infrastructure to military capability and capacity while the United States does not appear to view the Arctic as a near-term military priority (Aerandir, 2012). After analyzing the growing activity and interest in the region, as well as recognizing that the Department of Defense (DOD) is one of many federal organizations experiencing a challenging fiscal environment, we feel that it is only natural to ask what it would cost to enable the Surface Navy to operate successfully in the Arctic in the future.

A. ARCTIC ENVIRONMENT

Ice coverage in the Arctic is decreasing, sea-lanes are becoming more accessible and the possibility of discovering unknown oil and natural gas reserves is high (Boeing Phantom Works, 2011). Over the past 30 years, there has been a notable decline in ice coverage throughout the Arctic (Tomaszek, Bassler, & Nichols, 2014), summarized in Figure 1. Additionally, the U.S. Geological Survey of 2008 estimates that 13% of the world's undiscovered oil and 30% of its natural gas remain in the Arctic (Tomaszek et al., 2014). This estimation, coupled with the decreasing ice coverage, motivates more companies to explore the Arctic at an increasing rate.

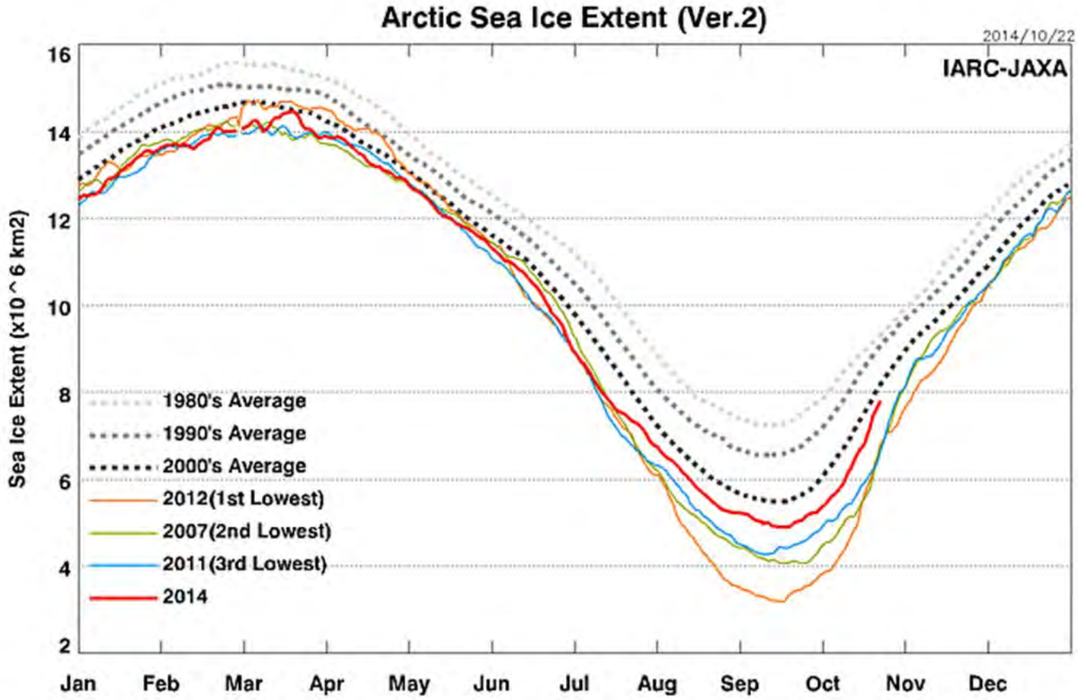

Figure 1. Decade Average and Current Sea Ice Extent (from Japan Aerospace Exploration Agency, 2014).

A recent report published by the Government Accountability Office (GAO) (2014) estimates that, over the next decade, surface traffic in the Arctic will be minimal due mainly to environmental challenges and a lack of infrastructure. Nevertheless, state and private stakeholders are making plans and preparing for increased traffic in the region based on the decreasing ice coverage (GAO, 2014). Increased traffic increases the probability of an incident or disaster. Further complicating the problem is the limited infrastructure in the region. In many areas, the nearest hospital is several hundred miles away, perhaps even farther depending on the severity of the injury or the capacity limitations of the facility (Tomaszek et al., 2014).

Based on the historical ice data in Figure 1, the Arctic is presumed to be open for transit between the summer months of August and September with partial access in July and October, defined as shoulder months (Tomaszek et al., 2014). Beyond the limitations of the ice coverage, the average temperature in the Arctic is rarely above freezing with, on average, only one or two days a month having high temperatures above freezing

during the summer (Tomaszek et al., 2014). A report issued by the Office of the Under Secretary of Defense for Policy (OUSD(P)) further expands on the challenges of operating a surface vessel in the Arctic due to the potential of a ship being trapped by wind-blown ice, superstructure icing affecting stability, and unpredictable dense fog and weather formations (OUSD(P), 2011). In short, operating in this environment is secondary to simply surviving.

B. ARCTIC GEOPOLITICAL SITUATION

The very definition of what constitutes the Arctic is not widely shared. The astronomical view of the Arctic includes everywhere that has at least one day of 24-hour sunshine (Boeing Phantom Works, 2011). Congress's Arctic Research and Policy Act definition includes Alaska's Aleutian Islands, making it the most inclusive definition. Climatologists define the Arctic based on average monthly temperature records being less than 10 degrees, ecologists based on the Arctic tree line boundary, hunters and fishers based on "permafrost"[1] coverage, and anthropologists base their definition on the furthest outreach of indigenous tribes and cultures (Boeing Phantom Works, 2011).

While many definitions exist, for the purpose of this project, we are going to mirror DOD's definition of the Arctic as anywhere north of 66°N latitude (see Figure 2) (O'Rourke, 2014). This area is important to this study because it includes the two primary shipping lanes used in the Arctic, the Northern Sea Route (NSR), which parallels Russia's northern border, as well as the Northwest Passage (NWP), which parallels Canada's northern border and the northern coast of Alaska. Both of these routes utilize the Bering Strait between Alaska and Russia, but they represent the highways of the Arctic and contain the majority of the sea traffic in the region (see Figure 3).

[1] Land that remains frozen throughout the year.

Figure 2. Arctic Region (from Central Intelligence Agency, 2014b).

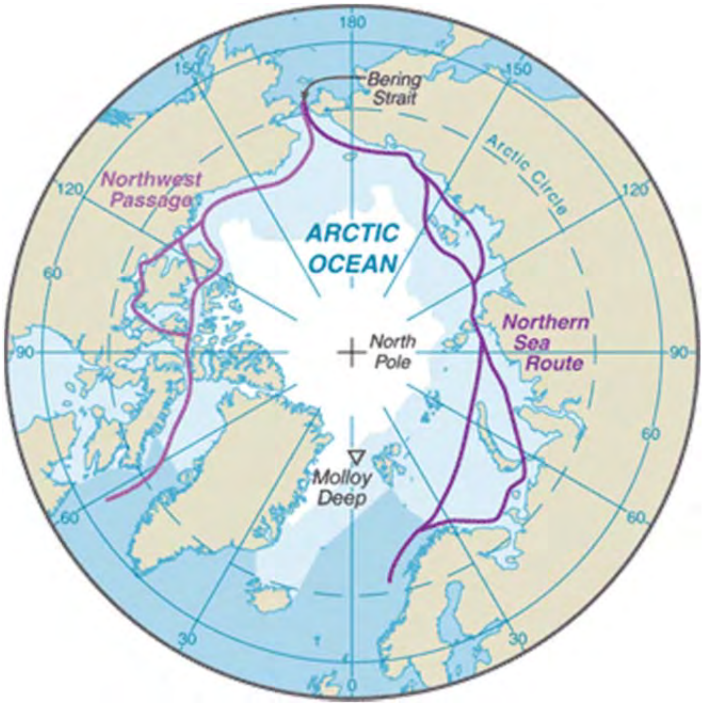

Figure 3. Arctic Circle (from Central Intelligence Agency, 2014a).

Eight countries have a direct or indirect stake in Arctic matters. Directly, the United States, Russia, Norway, Denmark (via Greenland), and Canada all have a sovereign Arctic Ocean shoreline (Arctic Council, 2014). Indirectly, Finland and Sweden have territory within the Arctic, and Iceland has an Exclusive Economic Zone[2] that is also within the Arctic Circle. These eight countries comprise the Arctic Council; an inter-governmental organization that was formed in 1996 to address pertinent Arctic matters diplomatically. The Arctic Council chairmanship is shared by all of the member-countries listed above, with the position rotating every two years (Arctic Council, 2014).

In addition to the eight member-countries, several resident indigenous populations are represented in the Arctic Council as permanent participants. Each of the eight member-countries, with the exception of Iceland, has at least one indigenous population represented in the Council (Arctic Council, 2014).

[2] Exclusive Economic Zones will be discussed later in the chapter.

In addition to semi-annual meetings, all Arctic Council representatives assemble every two years in what is called a Ministerial Meeting to recap the past two years' events and vote on future projects/priorities (Arctic Council, 2014). Several nations have been approved to attend these meetings as permanent observer-nations as long as their status is approved by a vote of the member-countries. In 2013, the member-countries granted observer status to China, India, Italy, Japan, Singapore and South Korea. These six countries join the original six observer-nations including, France, Germany, Netherlands, Poland, Spain, and the United Kingdom. These observer-countries have no voting rights in the Arctic Council; they only receive invitations to meetings and they are provided with information about Arctic Council operations (Arctic Council, 2014).

While the Arctic is difficult to define geographically, it is also difficult to divide into areas of jurisdiction for the purpose of establishing, among other things, rights and responsibilities to economic claims or designating a transit authority for shipping. The 1994 United Nations Convention on the Law of the Sea (UNCLOS) is the guiding authority behind this division of rights, and while the United States has yet to ratify this treaty, it does comply with nearly all of the rules. The UNCLOS defines areas of sea and the corresponding sea floor that coastal nations have rights over and to what extent (see Figure 4) (UN, 1994).

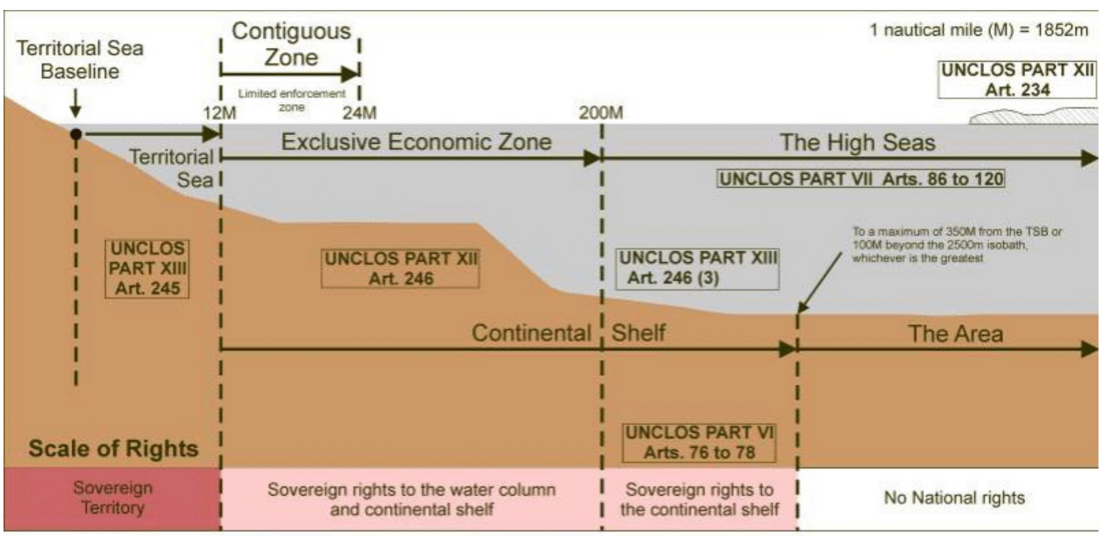

Figure 4. Coastal Maritime Zones (from National Oceanographic Center, Southampton, 2014).

Three main maritime zones are defined under the UNCLOS: Territorial Sea, Exclusive Economic Zone (EEZ), and The High Seas. Territorial Seas extends 12nm (nautical miles) from a nation's base-coastline covering the sea floor, the seawater, and the air above as sovereign area (UN, 1994). In short, the coastal nation has complete authority out to 12nm with limited "chase" authority out to 24nm, which is classified as a country's Contiguous Zone. Defining where a nation's coastline begins, Territorial Sea baseline, is difficult for some countries that have many small islands or archipelagos surrounding their country. Many nations use their island territories to unrightfully extend their Territorial Sea baseline to claim more sovereign Territorial Sea coverage (UN, 1994).

A country's EEZ extends from 12nm out to 200nm, with sovereign rights to the seawater and sea floor (UN, 1994). Within an EEZ, a country has rights to all resources within the sea, including fish and wildlife, and beneath the seafloor, including mineral and gas deposits. The EEZ is primarily different from a country's Territorial Sea because a country cannot limit traffic on the surface of the ocean, as long as it is routine in nature (UN, 1994).

Beyond the EEZ, a country may have economic rights to the resources of the seafloor, or continental shelf, as long as it can prove that that continental shelf is a continuation of the nation's seabed (UN, 1994). For the UN to agree to this excessive continental shelf claim, the nation must prove two things: 1) that the continental shelf is part of a naturally occurring geological shelf originating in its waters and 2) that it extends beyond 200nm from its Territorial Sea baseline (UN, 1994). If they successfully prove to the UN that a particular continental shelf meets both of these criteria, they may retain rights to the natural resources within the seafloor, but only out to a maximum of 350nm from their Territorial Sea baseline (UN, 1994).

With the exception of natural continental shelf extensions, the area beyond 200nm from a nation's Territorial Sea baseline is considered The High Seas (UN, 1994). No nation has control over The High Seas, and all vessels have complete freedom of navigation. Within The High Seas, the seafloor and resources contained therein comprise what the UNCLOS classifies as The Area. No nation has direct rights to The Area, but

the resources within may be explored by anyone subject to approval by the International Seabed Authority (ISA). The ISA, established by the UNCLOS Part XI, also controls the royalty distribution as a result of such exploration (UN, 1994).

The UNCLOS treaty became effective in November 1994 and has since been ratified by 60 nations and signed by 157 nations (UN, 1994). The United States has yet to ratify the treaty, taking issue primarily with Part XI, mentioned above. The United States claims that Part XI adversely affects American economic interests from its coasts. Nevertheless, the U.S. has recognized the remaining parts of the treaty as legitimate international law and routinely complies with the rules stated therein (UN, 1994).

In addition to the maritime zones delineated above, the EEZ boundaries between coastal nations are also guided by the UNCLOS (UN, 1994). Generally, common sense prevails in these negotiations with both neighboring countries agreeing to a straight and equal baseline between sovereign claims, but the Arctic involves two unresolved EEZ boundary disputes. Currently, Canada disputes both its eastern EEZ boundary with Denmark as well as its western EEZ boundary with the United States in the Beaufort Sea. Naturally, both disputes revolve around the potential presence of natural resources, including oil and natural gas. While these disputes are merely diplomatic debates now, the potential for increased tension is possible as more resources are confirmed and infrastructure development takes place (Boeing Phantom Works, 2011).

1. National Arctic Policy and Strategy

Just before the end of his final term, President George W. Bush signed an Arctic Presidential Directive that served as both National Security Presidential Directive-66 (NSPD-66) as well as a Homeland Security Presidential Directive-25 (HSPD-25) (United States White House, 2009). The document, hereafter referred to as the Arctic Policy, outlined America’s security policy intentions for the Arctic Region. President Bush’s priorities in the directive were stated as follows:

1. Meet national security and homeland security needs relevant to the Arctic region;

2. Protect the Arctic environment and conserve its biological resources;

3. Ensure that natural resource management and economic development in the region are environmentally sustainable;

4. Strengthen institutions for cooperation among the eight Arctic nations (the United States, Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, and Sweden);

5. Involve the Arctic's indigenous communities in decisions that affect them; and

6. Enhance scientific monitoring and research into local, regional, and global environmental issues (United States White House, 2009, para. III.A.).

The Arctic Policy included missile defense and early warning, deployment of sea and air systems for strategic sealift, strategic deterrence, maritime presence, maritime security operations (MSO), and ensuring freedom of the seas as national security matters within the Arctic (United States White House, 2009). Additionally, the Arctic Policy addressed prevention of terrorism, including the mitigation of vulnerabilities to terrorism, as homeland security matters. President Bush called for the United States Senate to ratify the UNCLOS treaty to enable the United States to have a seat at the table when maritime claims were negotiated and/or disputed (United States White House, 2009). Lastly, the president promoted safe scientific exploration in the region with the expectation that it would be done in cooperation with local populations and protect the natural environment (United States White House, 2009).

In May 2013, President Obama signed the National Strategy for the Arctic Region, which effectively gave the Arctic Policy a strategic framework (United States White House, 2013). The National Strategy outlined an overarching agenda for many facets of government, including the DOD. The document defined three lines of effort supported by four guiding principles:

Lines of Effort

1. Advance United States Security Interests

2. Pursue Responsible Arctic Region Stewardship

3. Strengthen International Cooperation

Guiding Principles

1. Safeguard Peace and Stability

2. Make Decisions Using the Best Available Information

3. Pursue Innovative Arrangements

4. Consult and Coordinate with Alaska Natives (United States White House, 2013, pp. 2–3)

This project is directly tied to the president's first line of effort, directing the United States to be able to operate "through, under, and over the airspace and waters of the Arctic, support lawful commerce, achieve a greater awareness of activity in the region, and intelligently evolve our Arctic infrastructure and capabilities, including ice-capable platforms as needed" (United States White House, 2013, p. 2). This is a known operational weakness of the United States and one that is shared with the Nation's Arctic neighbors.

President Obama's Arctic Strategy clearly acknowledges that the Arctic is a changing environment experiencing warmer temperature cycles and increased human traffic (United States White House, 2013). Additionally, it emphasizes, that while the resources and economic interests in the region are appealing, the United States must proceed with patience and the unyielding commitment to the indigenous population and local environment. Naturally, the Arctic Strategy also states that the number-one priority is the protection of the United States people and the Nation's sovereignty over its Arctic resources and territory. Couched in collaborative language, the president focuses on working with all of the Arctic nations to ensure that the Arctic remains an area of cooperation and opportunity versus an area of conflict and dispute. Lastly, President Obama mirrors President Bush by calling for the United States to ratify the UNCLOS treaty, stating that the United States is the only Arctic Council nation without a seat at the negotiation table as other Arctic nations, specifically Russia and Canada, proceed with maritime boundary and excessive continental shelf negotiations (United States White House, 2013).

2. Defense Department Arctic Policy and Strategy

Subsequent to the president's National Arctic Strategy, the Secretary of Defense released DOD's Arctic Strategy (DOD, 2013a). DOD's strategic framework is expressed in terms of realistic expectations and the opportunity costs of acting now versus when the ice caps melt even further, enabling more traffic in the Arctic. As the DOD strategy states:

> The Department's strategic approach to the Arctic reflects the relatively low level of military threat in a region bounded by nation States that have not only publicly committed to working within a common framework of international law and diplomatic engagement, but have also demonstrated the ability and commitment to do so. In consideration of enduring national interests in the Arctic and existing strategic guidance, the Department's end-state for its strategic approach to the Arctic is: ***a secure and stable region where U.S. national interests are safeguarded, the U.S. homeland is protected, and nations work cooperatively to address challenges*.** (DOD, 2013a, p. 4; italics in the original)

Furthermore, DOD recognizes that the Nation's objectives in the Arctic will continue to adjust based on global priorities and fiscal constraints (DOD, 2013a). While the U.S. State Department is primarily concerned with diplomatic relationships, DOD acknowledges that they play a significant role in furthering international relationships when it comes to Arctic operations, specifically operations involving disaster relief or humanitarian assistance (DOD, 2013a).

To reach its desired end-state, DOD lays out a series of priorities. First, DOD plans on building and sustaining strategic partnerships with allies in the region. By capitalizing on low-cost multi-national exercises, the United States can build and sustain relationships with Arctic allies that will pay dividends in the future (DOD, 2013a). Exercises, including Greenland's Search and Rescue Exercise (SAREX), Norway's COLD RESPONSE and Canada's Operation NANOOK, all represent fruitful training opportunities for the U.S. military while also building diplomatic relations (DOD, 2013a).

Secondly, DOD has tasked the United States Northern Command (NORTHCOM), as the main Arctic advocate, with identifying capability gaps and

requirements in the Arctic region (DOD, 2013a). While benefiting from "lessons learned" during Arctic exercises, NORTHCOM has been directed to collaborate with other Combatant Commands and various military departments to compile a comprehensive list that prioritizes DOD's focus. This list will highlight which operational gaps the United States should focus on in the near-term (present +10 years), mid-term (present +20 years) and far-term (beyond 2030) (DOD, 2013a).

Additionally, DOD's Arctic Strategy includes collaborating with other federal departments to understand the changing Arctic environment (DOD, 2013a). DOD can greatly benefit from a thorough understanding of the Arctic ice coverage trends as it times future investments. Sound scientific research allows DOD to apply an increasing level of effort and funding toward the Arctic as the regional traffic increases, while allowing the department the luxury of devoting precious fiscal assets elsewhere in the near-term. An additional benefit to this strategy is that it allows potential missions in the Arctic to become clearer to DOD. Sweeping changes toward a much more robust Arctic presence now can have drastic long-term implications and severely weaken the Nation's ability to answer unexpected contingencies (DOD, 2013a).

Diplomatically, DOD also supports ratification of the UNCLOS treaty as it allows for nations to peacefully negotiate and divide natural resource rights and responsibilities (DOD, 2013a). Beyond the UNCLOS, DOD also fully supports advancement of the Arctic Council, because it serves a critical role in encouraging cooperative problem resolution in a region that has the potential of becoming hotly contested (DOD, 2013a).

a. Defense Department Arctic Strategy Challenges and Risks

At the conclusion of DOD's Arctic Strategy, the department articulates four challenges or risks to its strategic framework.

First challenge: "Projections about future access to and activity in the Arctic may be inaccurate" (DOD, 2013a, p. 12). While DOD does not disagree that the Arctic environment is changing at a rapid rate, it remains skeptical about the rate at which human activity would increase commensurate with the receding ice coverage. In line with its stated intention of leveraging scientific research to benefit investment timing,

predicting the rate of increased human activity in such an environmentally hostile area of the world is extremely difficult (DOD, 2013a).

Second challenge: "Fiscal constraints may delay or deny needed investment in Arctic capabilities, and may curtail Arctic training and operations" (DOD, 2013a, p. 12). Understanding the sentiment of the United States after over a decade of war and conflict, DOD predicts that budgetary constraints will continue to increase. This downward fiscal pressure may force the department to dismiss Arctic opportunities in the near-term to satisfy larger more pertinent demands (DOD, 2013a).

Third challenge: "Political rhetoric and press reporting about boundary disputes and competition for resources may inflame regional tension" (DOD, 2013a, p. 13). Again, DOD recognizes that certain uncontrollable factors may spoil its strategic intentions of cooperation through existing diplomatic channels. Naturally, the chance exists that actions by the press will have unintentional, negative consequences. The significant risk comes into play when, or if, the United States is unable to handle an Arctic conflict/contingency that may have been plausible but not probable. If the press unintentionally turns a plausible event into an actual event, DOD maintains that it will be ready to achieve the mission (DOD, 2013a).

Fourth challenge: "Being too aggressive in taking steps to address anticipated future security risks may create the conditions of mistrust and miscommunication under which such risks could materialize" (DOD, 2013a, p. 13). DOD does not want to be the source of a self-fulfilling prophecy and potentially cause an "arms race" by rapidly changing Arctic force structure and capabilities. Without a clear and compelling need to build Arctic-capable military assets, DOD is hesitant to proceed faster than its current rate for fear of sending the wrong message to fellow Arctic nations (DOD, 2013a). DOD appears to be very sensitive to the regional diplomacy and cooperation that appears to be working well right now.

3. Department of the Navy Arctic Policy and Strategy

Subsequent to the Arctic Strategy set forth by DOD, the Chief of Naval Operations (CNO) released its Policy Guidance and National Interests for the Arctic

region (CNO, 2014). The Navy recognizes that it plays a pivotal role in the Arctic as the maritime component of DOD. Furthermore, the Navy has updated the 2009 Navy Arctic Roadmap to provide guidance on how it will respond effectively to future Arctic Region contingencies. This updated roadmap aims to support both the National and DOD objectives for the United States within the Arctic region. The Navy's primary goal is to contribute to a peaceful, stable and conflict-free Arctic Region (CNO, 2014). The Navy will pursue the following strategic objectives to meet these aims:

1. Ensure United States Arctic sovereignty and provide homeland defense;
2. Provide ready naval forces to respond to crisis and contingencies;
3. Preserve freedom of the seas; and
4. Promote partnerships within the United States government and with international allies and partners (CNO, 2014, p. 3).

To ensure these strategic objectives become a priority in current operations, the Navy will continue to fill high-ranking leadership positions in the Arctic Region to assist in increasing joint interoperability between allied nations and the interagency community (CNO, 2014). This continues to be an imperative aspect of the Navy's strategic goals in the hard-to-reach, inaccessible, and harsh environment of the Arctic. This leadership presence will pursue improved Maritime Domain Awareness (MDA), meteorological and oceanographic information, and safety of navigation. As DOD chief agent for MDA, the Navy plays a major role in continuing interagency and international efforts to share maritime information with our partners (CNO, 2014).

Accordingly, the Navy has been delegating appropriate funding to "maximize the safety and effectiveness of maritime vessels, aircraft, and forces of the armed forces" (CNO, 2014, p. 17). These Title 10 responsibilities will also contribute to the execution of key missions engaging U.S. joint forces, interagency stakeholders, and allied partners to protect the aims delineated in the National and DOD Strategic Arctic Strategies (CNO, 2014).

The Navy has identified six key functions and missions that will support the National and DOD strategies:

1. Maritime Security
2. Sea Control
3. Power Projection
4. Freedom of Navigation
5. Search and Rescue (SAR)
6. Disaster Response/Defense Support of Civil Authorities (DSCA) (CNO, 2014, pp. 17–18)

In the near-term (2014–2020) the Navy plans to continue operating in the Arctic with undersea and air assets while maintaining necessary training and personnel to respond to contingencies and emergencies affecting national security (CNO, 2014). The Navy will improve its capabilities by participating in increasingly complex exercises and training with regional partners. In the far-term (beyond 2030) the Navy will be capable of sustained operations with the ability to achieve desired Combatant Commander's objectives (CNO, 2014).

Naval forces will see an increase in Arctic operations as ice coverage in the Arctic undoubtedly diminishes and navigable waterways become more accessible for longer periods of time (CNO, 2014). This force will be ready to respond to any potential threat to national security, or to provide contingency response. The Navy will take deliberate steps to anticipate and prepare for Arctic Region operations in the near-term (2014–2020), mid-term (2020–2030), and far-term (beyond 2030). The key will be to balance potential investments with other priorities (CNO, 2014).

C. CURRENT ARCTIC SURFACE CAPABILITIES

No blue-water Navy, including the U.S. Navy, has ice-class[3] or icebreaking combatant ships in their fleet; the United States has a ice hardened tanker-class of ships, but they are not combatants (OUSD(P), 2011). While it is uncertain when surface

[3] See Appendix A for an explanation of various Polar Class distinctions.

combatants may, if ever, be required in the Arctic, there are a number of countries whose respective coast guards operate icebreakers and other polar class vessels on a regular basis. Amund Lundesgaard, a Norwegian Institute for Defense Studies' research fellow, states, "No navies have ice capable combat ships, and as far as I know, there are no plans to build such ships either. Consequently, naval presence in the arctic will be seasonal for decades to come" (Evans, 2013, para. 5).

Given the harsh operating environment in the Arctic, it can be argued that a nation is better able to make a national statement in the Arctic with their support and rescue abilities rather than their power projection with Arctic battle-groups and weapon systems (Evans, 2013). Regardless, an Arctic prepared Navy could be a robust support and rescue asset *as well as* being an instrument for national security if a conflict situation arises.

The United States Coast Guard (USCG) has two operational icebreakers in their fleet, the heavy icebreaker Coast Guard Cutter (CGC) Polar Star (WAGB-10), and the medium icebreaker CGC Healy (WAGB-20) as well as a handful of ice class tugs and tenders (USCG, n.d.). Previously the USCG operated a second heavy icebreaker, the CGC Polar Sea (WAGB-11), but it is not currently operational and there are no firm plans in place to return the Polar Sea to the fleet at this time (USCG, n.d.).

According to LCDR Ariel Piedmont, Operations Officer in CGC Polar Star, traditionally Polar Star and Healy split missions between the northern Arctic region and Antarctica to the south. Most commonly the Polar Star performs a winter deployment to Antarctica to groom an ice channel for supply ships to access McMurdo Station, a research facility on the southern tip of Ross Island located south of New Zealand in the McMurdo Sound. Additionally, Healy is more often tasked with missions in the northern Arctic with both ships regularly supporting research detachments onboard (A. Piedmont, personal communication, September 5, 2014).

Beyond these operational requirements, both ships are required to complete thorough maintenance cycles after every icebreaking mission, including an extensive dry-docking period, to perform necessary repairs and inspect the ship for any damage. Traditionally Healy has been dry-docked every other year, with Polar Star being dry-

docked after her Antarctica mission, but with Polar Sea no longer in service, Polar Star is scheduled to make annual Antarctica trips with associated dry-dock periods yearly (A. Piedmont, personal communication, September 5, 2014).

Lastly, the largest source of armament on either vessel is limited to crew-served weapons commonly used for force-protection while getting underway and entering port (A. Piedmont, personal communication, September 5, 2014). With these existing operational and maintenance strains on Polar Star and Healy, the USCG, without a significant financial investment, is not in a position to take on additional Arctic tasking commensurate with the existing glide slope of increased Arctic activity and exploration.

D. ARCTIC SURFACE SHIP BASING

Of critical importance when operating in the Arctic are logistic hubs and bases. Figure 5 displays key locations where current bases exist, Everett, Washington, and Kodiak, Alaska, as well as civilian port facilities in, Nome, Alaska, and Barrow, Alaska (Tomaszek et al., 2014). In a report issued by the United States Army Corps of Engineers (USACE), the state of Alaska, in conjunction with federal agencies and local officials, recognizes the need for additional deep-water port capabilities along the Alaskan coast. While still in the planning phase, the facilities at Nome and Barrow have been identified as prime candidates for port construction to support larger shipping traffic (USACE, 2013).

The closest base that can fully support naval vessels operating in the Arctic is Everett, which is approximately 1800nm, roughly a five-day transit from the Bering Strait (Tomaszek et al., 2014). Further to the north is the USCG Air Station in Kodiak, but the port facilities are only able to support small- to medium-sized vessels requiring further infrastructure development to support/fuel larger vessels. Beyond these two facilities, Nome is the most capable location providing anchorages for vessels up to 1000ft with a maximum draft of 40ft. Barrow can also support small- to medium-sized vessels at anchorages off the coast, but the facilities are slightly more rudimentary than in Nome (Tomaszek et al., 2014).

On the near-term need for additional Arctic infrastructure, the OUSD(P) states:

> With the low potential for armed conflict in the region in the foreseeable future, the existing defense infrastructure (e.g., bases, ports, and airfields) is adequate to meet near- to mid-term U.S. national security needs. Therefore, DOD does not currently anticipate a need for the construction of additional bases or a deep draft port in Alaska between now and 2020. (OUSD(P), 2011, p. 25)

While this stance will naturally be reassessed in the future because of the long lead-time on infrastructure construction, for now, beyond mooring pierside in Everett, a ship's ability to receive fuel/stores/parts in the Bering Sea and surrounding Arctic area would require additional services such as fuel barges or air support while anchored (OUSD(P), 2011). Underway replenishment could be a possibility provided an oiler is available, the sea-state allows, and there is a lack of ice present for the operation.

Figure 5. Map of Current Northern Military Bases and Alaskan Ports (from Tomaszek et al., 2014).

II. METHODOLOGY AND SCOPE

First, we defined all mission sets required to meet the changing environment and potential diplomatic, informational, economic, and military threats that will exist in the Arctic. For example, in President Bush’s Arctic Policy, Arctic missions for surface forces may take the shape of missile defense and early warning, or more homeland defense in nature with the mitigation of vulnerabilities to terrorism in the north (United States White House, 2009). Combining existing policy guidance such as this from the president and DOD with a hypothetical Russian expansionism scenario outlined below, we narrowed our focus to missions that the Surface Navy could get tasked with in the future.

With these surface missions defined, we identified an Arctic vessel concept capable of achieving these designated missions by looking at altering existing platforms in the U.S. fleet or building a new class of ships. While this project attempts to focus on the cost estimation to the Navy’s surface forces, we acknowledge that surface combatants are merely one piece of a much more complicated mission package should conflict arise in the Arctic.

After discussions with naval architects, we determined that the feasibility of modifying an existing ship to make it Arctic-capable would quickly become cost prohibitive because of the invasive modifications needed throughout the ships hull, essentially requiring a complete hull redesign and fabrication (W. Solitario and F. Papoulias, personal communication, October, 2014). Therefore, our cost estimation was narrowed to focus on the acquisition of a new Arctic-capable platform class of ships. In formulating an Arctic asset capable of accomplishing the missions we defined, we capitalized on existing Arctic platform designs from other nations, explained in more detail later, including the recent Canadian Arctic Offshore Patrol Ship (A/OPS) project, the Norwegian Svalbard Icebreaker/Offshore Class and the Denmark Knud Rasmussen Offshore Class of ships. After the identification of a suitable Arctic platform concept, a cost estimation was performed to display the likely acquisition costs to the U.S. Navy in the future.

Lastly, we leveraged contacts from allied Arctic countries as well as Combatant Commands (IE NORTHCOM, PACOM) and the Coast Guard to analyze the missions, platform concepts and mission priorities. In line with the predicted missions, these contacts helped in providing guidance, cost information and estimates that were used to estimate the cost of our Arctic platform concept.

A. RUSSIAN EXPANSIONISM SCENARIO—CHINESE ARCTIC MOTIVATION

The following scenario is hypothetical and was used in a Joint Campaign Analysis course at the Naval Postgraduate School to describe the geopolitical arena if Russia continues to expand its interests in the Arctic region. As mentioned previously, the missions defined later in this chapter were devised through the lens of this scenario and guided by existing executive and defense policy documents.

As the Arctic becomes more accessible, the emerging threat of Russian expansionism becomes increasingly plausible (Kline, 2014). Conflict in the Arctic could formulate as Russia continues to expand and posture forces while seeking economic resources that are in contested geographic areas. A possible scenario exists where over the next several years Russia's economy is strengthened significantly due to growing seasons of more temperate weather and eased access into their northern oil fields. Because the NSR and NWP will be open for three to four months during the summer, and continually increasing in length each year thereafter, Russia will have much easier access from their eastern boarders to both Europe and North America (Kline, 2014).

This scenario includes a nuclear powered North Korea that is finally pacified by a large financial buyout and the United States initiating a force drawdown from the Korean peninsula in 2018 with no forces remaining by 2021. Relationships between Russia and China have drastically improved and Russia sees no threat to Siberia (Kline, 2014).

By 2025, Russia's economy will reach unprecedented growth where they have broken into the top five economies in the world (Kline, 2014). Russia has leveraged their oil exports to obtain engineering technologies from both Germany and France while simultaneously spending significant amounts of money automating and modernizing their

naval and air forces. This modernization includes a collaboration project with China to develop advanced weapons systems (Kline, 2014).

Russia intends to use its military and project its power by taking over the Swedish island of Gotland in the Baltic Sea (Kline, 2014). Russia's intended goal is to increase its control over shipping and natural resources in the Baltic Sea (Kline, 2014). This plan opens significantly more port space within the Baltics for porting ships and gives Russia greater situational awareness of the maritime approaches to Stockholm, St Petersburg, Tallinn, Riga, Kaliningrad and Gdansk. Russia is also making plans to invade the Kuril Islands, which give them the advantage of strategic positioning to monitor maritime traffic in the vicinity of the Sea of Okhotsk (Kline, 2014). Control of these islands would allow Russia an extremely viable supporting port for its ships that are patrolling the entrance to the Arctic NSR (Kline, 2014).

In addition to expanding the range and capacity of its maritime operations, Russia is enforcing its extended continental shelf claims without UN resolution (Kline, 2014). The move is contentious as Russia claims the Lomonosov and Medeleev Ridge, including the North Pole, as an extension of the Asian continental shelf, while Canada claims that it is an extension of the North American shelf (Kline, 2014) (see Figure 6). Denmark also has issues with Russia's claim as Danish scientists hope to prove that the ridge is an extension of Greenland (BBC News, 2004).

At the very least, the Arctic has multiple overlapping interests involving numerous countries and will continue to become more contested as the region continues to open in the future (Aerandir, 2012). The possibility of these countries taking military action to secure and protect these interests increase as the resource disputes remain unresolved. While the majority of Arctic countries remain more interested in cooperation in the Arctic, it is recommended that the U.S. take a more involved role in the Arctic (Trent, 2011).

Russia is already much more prepared for increased Arctic operations than the U.S., which give it a comparative advantage in the region as human activity increases. Compared to the two USCG icebreakers in the U.S. fleet, Russia operates a fleet of 34

vessels, all capable of independent Arctic operations, including eight nuclear-powered heavy icebreakers (two being nonoperational), and two conventionally powered heavy icebreakers (OUSD(P), 2011). While the tonnage of ships operating in the Arctic is certainly in Russia’s favor, this is not surprising when you consider around half of all Arctic inhabitants (roughly two-million people) live along Russia’s 4,350-mile Arctic coastline. By necessity, this makes the NSR a vital passage for the Russian population to supply its Arctic inhabitants with food, stores, and other provisions (OUSD(P), 2011).

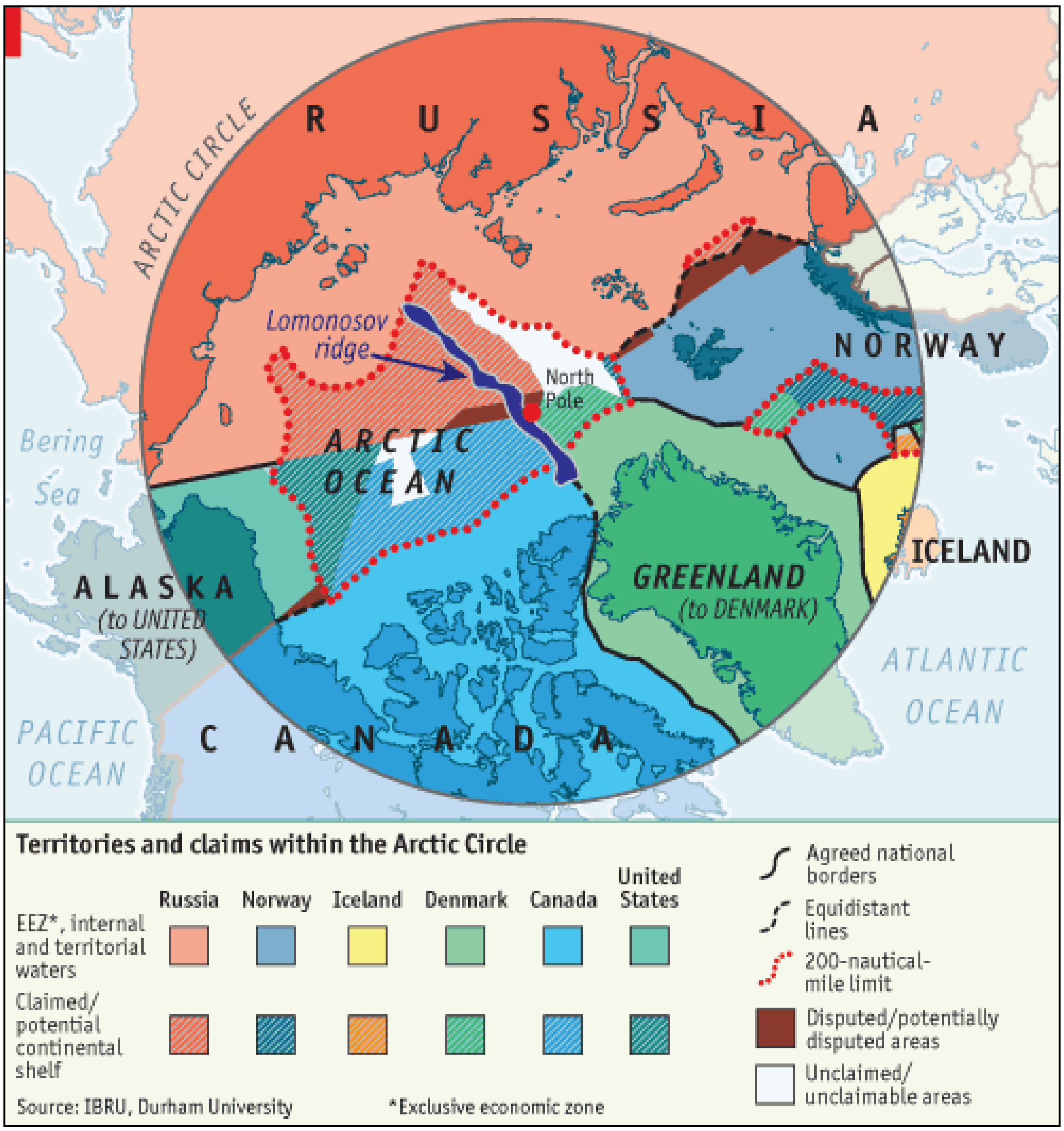

Figure 6. Territories and Continental Shelf Claims within the Arctic Circle (from The Economist, 2009).

Beyond this hypothetical scenario—recently, Professor Arbakhan Magomedov, Head of Public Relations Department, Ulyannovsk State University, Russia, was interviewed by Professor Wang Chuanxing, China's Center for Polar and Oceanic Studies (CPOS) Deputy Director concerning Russia's increasing concentration in the Arctic. He elaborated on the fact that Russia is focusing on capitalizing on two things in the Arctic: natural resource extraction and maritime transport through the NSR (International Studies on the Polar Region, 2014). Russia's Arctic regions and surrounding geography account for 98% of Russia's diamonds and 90% of its oil, gas, nickel, and platinum production (International Studies on the Polar Region, 2014). Not to mention the cost savings potentially realized by sending shipping through the NSR (International Studies on the Polar Region, 2014).

Furthermore, Professor Magomedov seconds the fact that Russia is in a unique position as the Arctic nation with largest Arctic population and coastline. This introduces further complications at the local level in how Russia manages and incorporates the large number of different local areas to maximize coordination in the region (International Studies on the Polar Region, 2014). Similar to Alaska, Russia's northern borders are home to a variety of local tribes and communities with different identities and accessibility levels. Likewise, it is easy to see Russia's expected logistical challenges in dealing with these local communities with the environmental conditions of the Arctic (International Studies on the Polar Region, 2014).

There remains the possibility that the Arctic will remain an area of cooperation for the foreseeable future. Since the publication of Figure 6, Russia and Norway have peacefully resolved their territorial border dispute in 2010 by dividing the acreage in half. Professor Magomedov candidly notes that both nations saw the compromise in their best interest to avoid increased European Union (EU) involvement in dictating how Arctic resources would be developed (International Studies on the Polar Region, 2014).

The interview concludes with both professors acknowledging that Russia and China could mutually benefit as Arctic partners. China's maritime interests in the Arctic, while not being an Arctic coastal nation, are very similar to Russia. China also sees potential in utilizing the NSR to cut shipping costs, while from a research perspective

China’s environment is significantly effected by Arctic weather patterns (International Studies on the Polar Region, 2014). This partnership could develop into increased tension among the other Arctic nations with Russia and China’s lack of transparency in diplomatic arenas. In short, Russia and China partnering could fuel tension in an area that is becoming more and more sensitive to the U.S. (International Studies on the Polar Region, 2014).

B. PROJECTED MISSIONS

The Obama Administration is in the process of approving an executive order that will establish an Arctic Executive Steering Group (AESG) (United States White House, 2014). The purpose of the AESG is to support U.S. Arctic Policy, ensure our nation is well positioned to protect its interests in the region and to strengthen relationships with the indigenous populations of the region. In short, the AESG is intended to calm the administrative confusion about the Arctic and serve as a central source of guidance instead of the fragmented network of think tanks already in place (United States White House, 2014). Within the AESG there will be five working groups, chaired by Deputy Secretary level positions or equivalent, tasked with specific roles and responsibilities to guide their discussions with Arctic partners. Tentatively the five working groups will be Security, Economic Issues, International Matters, Science and Research, and Environment (United States White House, 2014). Of those five, the Security Working Group is tasked with addressing the following national security interests in the Arctic:

- Missile defense and early warning
- Deployment of sea and air systems for strategic sealift
- Strategic deterrence
- Maritime presence
- Maritime security operations
- Ensuring freedom of navigation and overflight
- Preservation of the mobility of the United States military and civilian vessels and aircraft throughout the region, and

- Arctic domain awareness (United States White House, 2014)

The surface navy can certainly add value in achieving all of these missions, but our analysis focuses on a platform that is Polar Class (PC) 4/5 or greater and capable of conducting the following missions:

- Missile defense and early warning
- Deployment of sea and air systems for strategic sealift for humanitarian assistance and disaster relief (HADR), and
- Maritime security operations

Naturally, the mere presence and availability of U.S. Navy assets in the Arctic region will also help to ensure freedom of navigation and overflight depending on the tasking assigned. This project will outline an Arctic-capable platform concept that the Navy can invest in to conduct Arctic operations inline with these mission priorities.

C. COST ESTIMATION PROCESS

Government actions and policy decisions operate in a world of great uncertainty and rely heavily on educated predictions and estimations. Additionally, government policy decisions are generally unique to themselves and lack a competitive market elsewhere. In these situations a cost estimate is a useful tool in determining whether or not a government or federal department should proceed with a particular course of action or not.

1. Cost Estimate Methodologies

The four common methodologies for producing a cost estimate include:

- An estimate based on analogy
- Parametric modeling
- Engineering build-up
- Estimate based on actual cost data (Nussbaum, 2014)

There are advantages and limitations associated with each of the four techniques (see Table 1), but the selection of which methodology to use is more commonly dictated by where the project is in relation to its acquisition milestones (Nussbaum, 2014).

Table 1. Comparison of Cost Estimate Methodologies (from Nussbaum, 2014).

Model Category	**Description**	**Advantages**	**Limitations**
Analogy	Compare project with past similar projects	Estimates are based on actual experience	Truly similar projects must exist
Parametric Models	Perform overall estimate using design parameters and mathematical algorithms	Models are usually fast and easy to use, and useful early in the program. They are objective and repeatable	Models can be inaccurate if not properly calibrated and evaluated
Engineering Build-Up	Individuals assess each component; with component estimates summed to calculate the total estimate	Accurate estimates are possible because of detailed basis of estimate	Methods are time-consuming. Integration costs are sometimes disregarded
Actual Costs	Use historic cost data to estimate cost of continued production after initial production has begun	Highly detailed, accurate and verifiable	Inaccuracies may be due to changes in quantity, specific configuration of ship, raw material and labor cost inflation

The analogy or parametric modeling methodology is commonly the standard earlier in the program lifecycle, prior to Milestone B, due to the lack of engineering data available (see Figure 7) (Nussbaum, 2014). Consequently, at this point in the acquisition process of our Arctic concept vessel, a hybrid costing technique will provide the most accurate cost estimation. This hybrid approach will incorporate a parametric cost analysis of similarly designed Arctic-capable ships combined with an analogy estimate, utilizing the existing Arleigh Burke-class destroyer (Nussbaum, 2014).

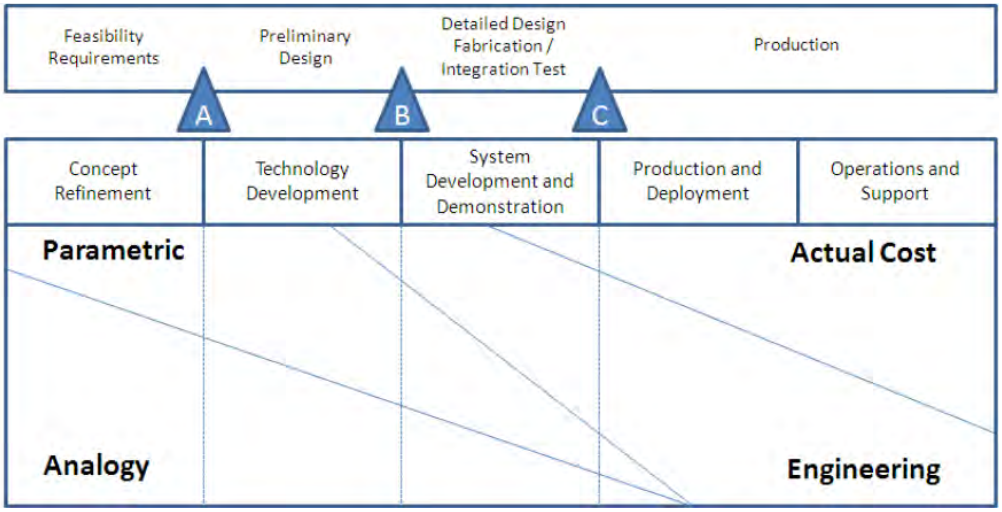

Figure 7. Cost Estimating Approaches with Respect to Acquisition Milestones (from Nussbaum, 2014).

2. Cost Estimating Steps

Regardless of the methodology utilized the following steps are commonly used: Collection of cost data from analogous historical situations; Normalization of the collected data to take account of historical inflation; Development of credible (often statistically-based) models; Modeling of the data to identify key cost drivers and their weight on the overall cost estimate; Sensitivity analyses in order to account for uncertainty and risks.

For the purpose of this project we will be adopting the cost estimating approach identified by GAO (2009). Outlined below is the nine-step process with project specific aspects included:

1. Define the estimates purpose: To estimate the Arctic platform concepts acquisition costs and schedule.

2. Develop the estimating plan: To conduct an initial cost estimation of the Arctic platform concept by leveraging historical cost information from similar existing ship classes, including various Arctic nations.

3. Define the program: Based on the mission analysis and timeline above we estimate that 3 Arctic platforms will be needed by 2025 with an additional 2 platforms completed by 2030.

4. Determine the estimating approach: This project is based on data availability and parametric analysis combined with an analogy approach taking into account the existing DDG design.

5. Identify ground rules and assumption: See section B of chapter 3.

6. Obtain the data: Cost and physical data were collected for various ships with similar design characteristics. See section C1 of chapter 3.

7. Develop the point estimate: The cost estimate was based on an iterative model utilizing cost data from numerous sources. All cost data figures were converted to U.S. dollars using the exchange rate on January 1 of the respective calendar year and subsequently standardized to FY15 dollars using the Naval Center for Cost Analysis (NCCA) inflation calculator. See section C2 of chapter 3.

8. Conduct sensitivity analysis: A sensitivity analysis was conducted using length, tonnage, and mission capability as key cost drivers to display the effect of possible design changes in the future. See section C3 of chapter 3.

9. Conduct risk and uncertainty analysis: After the point estimate was developed, a risk assessment was conducted and summarized in section C4 of chapter 3 (GAO, 2009).

III. COST ESTIMATION AND ANALYSIS

Based on the missions outlined above, we propose the U.S. Navy capitalize on its past shipbuilding design and knowledge to produce an Arctic-hardened destroyer, henceforth referred to as DDG/A, whose design is based primarily on the existing Arleigh Burke-class destroyer. As a multi-mission ship that the U.S. has been building since the 1980s, the DDG hull is relevant and potentially very useful in the Arctic environment with certain modifications.

A. ARCTIC PLATFORM CONCEPT

The Arleigh Burke-class destroyer (see Figure 9) superseded the Kidd-class (see Figure 8) and was built incorporating many lessons learned from her predecessor (Benson, 1998). The Kidd-class was 563ft in length with a beam of 55ft, a somewhat narrower concept ship design, which provided a more streamline posture in the water, but effectively decreased her capability in rougher waters (Benson, 1998). The Arleigh Burke-class, with a 505ft length and 66ft beam, was designed with a large water-plane area-hull form characterized by a wide flaring bow, which significantly improved sea-keeping ability (Benson, 1998). The hull form was designed to permit high speed in high sea-states and was initially intended for operations in the North Sea (W. Solitario, personal communication, October 7, 2014). The Arleigh Burke destroyer incorporated two layers of steel and 70 tons of Kevlar armor to protect the ship’s vital areas. The Arleigh Burke-class destroyer is smaller, broader, and more stable than both its predecessor and the Ticonderoga-class Aegis cruiser (Benson, 1998).

Figure 8. Kidd-Class Destroyer (DDG 993) (from Wikipedia, 2014).

Figure 9. Arleigh Burke-Class Destroyer (DDG 104) (from United States Surface Forces, 2011).

There are, however, many impediments to operating the current Arleigh Burke-class ships in the Arctic that would be improved in the DDG/A version. First, although there are two layers of steel in vital areas of the hull structure, the entirety of the hull is not PC rated, which precludes it from even partial Arctic operation in non-summer seasons or in any substantial first year ice (OUSD(P), 2011). Modifications to the hull's steel thickness as well as increasing the amount of scantlings, or hull frames, are required for the DDG/As survivability and operation in a sustained and continuous capacity in the Arctic region (International Association of Classification Societies, 2007). The DDG/A would be built to PC 5 standards with a PC 4 bow and stern for dual-action icebreaking going forward and astern. While the DDG/A would be able to sustain operations year round in first-year ice (approximately 4ft), the ship would *not* be considered an icebreaker and would require support from a conventional icebreaker should the mission require a DDG/A in more austere conditions (see Appendix A).

The hull redesign for the DDG/A would comprise the bulk of the modifications to the existing Arleigh Burke design. This redesign will require a strengthened rudder, propeller, and a reconfigured engineering plant incorporating a double-hull design with relocated seawater intakes, discharges, fuel/fluid tanks, and associated piping (Environmental Protection, 2009). While the exact design specifications are unknown at this point, the DDG/A's performance characteristics of speed and energy efficiency will likely be affected (OUSD(P), 2011). The commercial shipping world is already incorporating a single-hull phase-out program in favor of a double-hull with internally located fuel tanks to mitigate the risk of inadvertent fuel/fluid spillage from tanks along the skin of the ship (Environmental Protection, 2009).

Next, the hull mounted SONAR on the current design would prove less-effective in detecting traditional sub-surface threats in an ice-laden environment because of its close proximity to the surrounding ice drowning out any usable returns (W. Solitario, personal communication, October, 2014). Additionally, and arguably more important, the SONAR dome is susceptible to damage from the surrounding ice formations since it is only surrounded by a reinforced plastic and pressurized rubber dome enclosure. Therefore, the removal of the SONAR dome, as well as the associated SONAR combat-

systems suite, would drastically decrease the cost to procure the DDG/A. Additionally, cost savings would be realized in a smaller crew complement required to man the DDG/A. Lastly, this would decrease the draft of the ship increasing its accessibility into shallower ports in the Arctic region.

While there is certainly a subsurface aspect to the Arctic, with associated potential threats, the DDG/A concept is focused on accomplishing the stated missions above. Furthermore, the DDG/A concept could capitalize on utilizing old SONAR related spaces for additional medical facilities and storage space for Arctic cold-weather gear, which translates into greater sustainability and an increased HADR capability. The possibility of incorporating a towed-array SONAR into the design remains a possibility but is not included in the cost estimation of the DDG/A.

In estimating the cost of a DDG/A, we examined vessels from Arctic allied countries that were Arctic-capable offshore vessels. In addition to the vessels listed below, historical cost information from several other Arctic nations vessels was collected and normalized during the DDG/A cost estimation process. It is important to note that the DDG/A concept is not simply an offshore vessel like these listed below, but rather a more combat-capable ship that is similarly equipped to the existing Arleigh Burke-class and therefore able to achieve our designated mission-sets. Another way of framing the DDG/A concept is that the hull design, shape, and ice-hardened characteristics are similar to the three vessels listed below, but the combat-systems suite is more robust and modeled after the Arleigh Burke.

1. Canadian Arctic Offshore Patrol Ship Class

The Canadian Arctic Offshore Patrol Ship (A/OPS) class (see Figure 10) is a new design that has a number of capabilities that will allow the Canadian Navy to carry out their required missions in the Arctic region as they increase their focus on the Arctic. The A/OPS will be designed with a PC 5 hull and a PC 4 bow enabling the platform to operate year-round in first-year ice, up to one meter thick, which may include old ice inclusions (Barkel & Story, 2014). Although the A/OPS will have the capability to

maneuver in ice for sustained four-month operating periods, it will not provide icebreaking services (Barkel & Story, 2014).

The platform will have a competent command, control and communication capability to exchange real-time information with shore-based operations centers (National Defence and the Canadian Armed Forces, 2013). Additionally, the A/OPS will be capable of embarking and operating a variety of helicopter types as well as embarking and deploying a variety of boat types to support Arctic missions. Included in these activities are boarding operations and transfer of cargo and personnel for ship-to-shore transfer (National Defence and the Canadian Armed Forces, 2013).

Figure 10. Canadian Arctic Offshore Patrol Ship Concept (from Irving Shipbuilding, 2014).

2. Norwegian Svalbard Icebreaker/Offshore Ship

As the basis for the Canadian A/OPS design, the KV Svalbard (see Figure 11) is the largest ship in Norway's military armed forces (by tonnage) (Norwegian Armed Forces, 2014). Entering service in mid-2002, the Svalbard is outfitted with Nuclear, Biological, and Chemical (NBC) protection, a Bofors 56mm main battery, small-arm machine guns, basic surface RADAR, and the ability to embark up to two helicopters.

While she is modestly outfitted in weaponry, Svalbard is considered a double action ship designed to break ice both ahead and astern and can conduct icebreaking and emergency towing up to 100,000 tons (Norwegian Armed Forces, 2014). The Svalbard's simplistic design is reflected in its cheap price tag, approximately $85 million (Barkel & Story, 2014).

Figure 11. Norwegian Svalbard Icebreaker/Offshore Class (from Army Photos, 2012).

3. Denmark Knud Rasmussen Offshore Patrol Vessel Class

The first of two Knud Rasmussen Offshore Patrol Vessel (OPV) vessels (see Figure 12) that are now active was commissioned in February 2008 (Navy Technology, 2014). As one of the more combat-capable Arctic offshore vessels, the Rasmussen-class is armed with a 76mm Gun, 2 x 12 - 7mm Heavy Machine Guns, RIM-162 surface-to-air missiles, and ASW-torpedoes. However, the ship's normal operations consist of fishery inspections, environment protection, SAR operations, sovereignty enforcement, icebreaker assignments, and towage and salvage operations (Navy Technology, 2014).

The OPVs have thick hulls, an ice keel and an “ice knife” stem, as well as an ice strengthened rudder combining to increase her maneuverability in Arctic conditions. The hull is designed to break 40cm of normal sea-ice and 70cm of hardened multi-year ice with seawater intakes ingesting the broken ice as a usable cooling agent for her engines (Navy Technology, 2014). The Knud Rasmussen is the smallest and lightest offshore example at approximately 235ft and weighing only 1800 tons. Consequently this makes her the least ice-capable vessel when compared to the A/OPS and Svalbard (Barkel & Story, 2014).

Figure 12. HDMS Knud Rasmussen (P570) (from Defense Media Network, 2012).

B. POLICIES AND ASSUMPTIONS

The following list includes policies and assumptions surrounding the projected acquisition and cost estimation of the DDG/A class:

- The cost estimation will include all hull redesign and acquisition costs of the first 5 hulls (DDG/A 1–5) with projections out to a fleet of 10 hulls for illustrative purposes only.

- All cost figures are represented in FY15 U.S. dollars.

- The hull redesign phase begins in 2015.

- Construction of the first DDG/A will begin in January 2018 being completed by December 2018 with the second and third DDG/As starting construction in 2020 and 2022 respectively.

- Assumes 10% profit on the awarded contract with all associated taxes included.

C. COST ESTIMATION

Focusing on the missions of missile defense and early warning, strategic sealift for HADR, and MSO the DDG/A is a viable option for the U.S. Navy within the following cost estimations.

1. Historical Cost Data—First Units

Table 2 consolidates the, length, tonnage, and first unit cost information for the six ships used in conducting the DDG/A cost estimation. The first three ships listed in bold represent offshore ice-capable examples that compare to the DDG/A's concept hull design. In addition to these three ships, the historical cost information for the Arleigh Burke, Denmark's Iver Huitfeldt-class and Norway's Fridtof Nansen-class were included as applicable vessels with more robust combat capabilities albeit not as ice-capable.

Using a 95% learning curve, not uncommon in shipbuilding programs, each ship's first-unit (T1) historical cost data was converted to U.S. dollars and normalized to FY15 dollars (see Appendix B) prior to being consolidated into Table 2. Furthermore, statistical regressions were conducted (see Appendix C) in order to model these first unit costs to the following variables: cost per foot, cost per ton, and cost per mission rating. These regressions were done twice—once using only the three offshore ice-capable ships, and once using all six-ships listed. While all of the regressions failed to produce any

statistically significant relationships, the cost per foot regression (model 4) using all six-ships was the most acceptable model to use in calculating the cost of a DDG/A.

Table 2. First Unit Cost Comparison

	Length (ft)	Tonnage (Approx)	FY15 $M USD/T1 Unit
AOPS (Canada)	320	6400	**$741.75**
Svalbard-Icebreaker/Offshore Vessel (Norway)	340	6300	**$86.73**
Knud Rasmussen-Offshore Class (Denmark)	235	1800	**$89.97**
DDG 51 (U.S)	505	9000	**$2,142.20**
Iver Huitfeldt-Blue Ocean Arctic Class Frigate (Denmark)*	455	6,645	**$352.87**
Fridtjof Nansen-Frigate (Norway)	440	5,300	**$769.86**

*Price without Weapons

a. Mission Rating

While comparing physical characteristics of ships is revealing as part of developing a cost estimate, we wanted to capture the idea that the ships in our dataset were different with respect to their abilities to accomplish our designated missions. To this end we established a mission rating scale to rate how well each platform was suited to accomplish our designated missions. The scale in Table 3 was used to rate each ship giving them a score between 1-10 and displayed in Table 4.

Table 3. Mission Rating Scale

Mission Rating Scale	
0	No Ability to Conduct Designated Mission-Sets
1	Able to Conduct a Partial Mission-Set
2	Able to Conduct 1 Mission-Set Fully
3	Able to Conduct 1 Mission-Set Fully with Additional Partial Mission-Set Capability
4	Able to Conduct 2 Mission-Sets Fully
5	Able to Conduct 2 Mission-Sets Fully with Additional Partial Mission-Set Capability
6	Able to Conduct 3 Mission-Sets Fully
7	Able to Conduct 3 Mission-Sets Fully with Additional Partial Mission-Set Capability
8	Able to Conduct 4 Mission-Sets Fully
9	Able to Conduct 4 Mission-Sets Fully with Additional Partial Mission-Set Capability
10	Able to Conduct ALL Designated Missions

Table 4. Mission Rating Breakdown

Designated Missions	AOPS	Svalbard	Knud Rasmussen	DDG 51	Iver Huitfeldt	Fridtjof Nansen	DDG/A
Missile Defense and Early Warning			P	X	X	P	X
Strategic Sealift (HADR)	X	X		X	P	P	X
Ensuring Freedom of Navigation and Overflight	X	X	X	X	X	X	X
Maritime Security Operations (Including Embarkation of Helicopter)	X	P	X	X	X	X	X
Polar Class 4/5 or Greater	X	X	P				X
Mission Rating (X=Fully, P=Partial)	**8**	**7**	**5.5***	**8**	**7**	**5.5***	**10**
*Denotes 2 Partial Mission Areas							

A recognized weakness of this mission rating scale is that by weighing them equally we are assuming missions cost the same to achieve. While this is obviously not the case, it was used to illustrate the capability differences between platforms and to show that the DDG/A concept is envisioned to be the best equipped to handle the missions that we have prioritized. Additionally, as denoted by the asterisks, two ships were scored with half points because they were able to complete two missions partially, which does not make them eligible for the next higher score.

2. DDG/A Point Estimate and Learning Curve Predictions

After normalizing the historical cost data and analyzing the regression details a cost estimation was calculated utilizing the predicted design parameters of the DDG/A platform. Table 5 displays each ship’s T1 cost broken down across single feet, tons or mission ratings. Based on this information, and inline with a parametric cost estimation, an initial DDG/A would cost approximately $818.36 million as calculated by multiplying the average cost per foot into the predicted 505ft length of the DDG/A concept.

Table 5. Parametric DDG/A Cost Estimate

	Cost per Foot ($M)	Cost per Ton ($M)	Cost per Mission Rating ($M)	FY15 $M USD/T1 Unit
AOPS (Canada)	**$ 2.32**	$ 0.12	$ 92.72	$ 741.75
Svalbard-Icebreaker/Offshore Vessel (Norway)	**$ 0.26**	$ 0.01	$ 12.39	$ 86.73
Knud Rasmussen-Offshore Class (Denmark)	**$ 0.38**	$ 0.05	$ 16.36	$ 89.97
DDG 51 (U.S.)	**$ 4.24**	$ 0.24	$ 267.78	$ 2,142.20
Iver Huitfeldt-Blue Ocean Arctic Class Frigate (Denmark)	**$ 0.78**	$ 0.05	$ 50.41	$ 352.87
Fridtjof Nansen-Frigate (Norway)	**$ 1.75**	$ 0.15	$ 139.97	$ 769.86
Mean	**$ 1.62**	$ 0.10	$ 96.60	
	Length (ft)	**Tonnage**	**Mission Rating**	**FY15 $M USD/T1 Unit**
DDG/A Design (Predicted)	**505**	**9750**	**10**	**$ 818.36**

While this estimate is revealing, the accuracy and statistical relevance of the cost data for the foreign ships is recognized as being unreliable in providing a realistic cost estimate (Barkel & Story, 2014). Furthermore, many engineering factors about the DDG/A remain unknown, which allow for potentially drastic price fluctuations. Consequently, more calculations are required to complete a hybrid cost estimate as described earlier.

When design parameters are unknown, one approach to developing a cost estimate is to break the total ship design into workable pieces/percentages and estimate the costs of the individual sections as the ship's design becomes more concrete. As highlighted in Table 6, the CBO has published a construction cost breakdown guide for the DDG, which can be adjusted for the DDG/A (Ting, 2010).

Table 6. DDG-51 Construction Cost Breakdown (from Ting, 2010).

	% Cost DDG
Labor: Basic Ship Construction	41.20%
Material: Hull, Mech, and Electrical	35.20%
Material: Electronic, C4I	5.90%
Material: Defense Systems	17.70%
Total Construction	100%

Given CBO's construction breakdown, the price of a DDG/A will differ in two main categories. Primarily, the required hull redesign will be reflected in the "Material: Hull, Mechanical and Electrical" section comprising 35.2% of the total construction cost. Additionally, the removal of the SONAR combat-system suite will be reflected in a portion of the "Material: Defense Systems" section. While it is debatable as to how much the removal of the SONAR will affect the total construction cost, it is reasonable to assign 4.8% of the 17.7% in that section to the 35.2% already designated as being directly different than the existing Arleigh Burke-class. This 40% comprises the amount of *change* from the existing DDG design, the amount of cost uncertainty that can be attributed to similar Arctic platforms. In summary, this 60/40 split allows for a hybrid cost estimation to be completed on the DDG/A where 60% of the original Arleigh Burke's T1 cost is incorporated as an analogous cost portion with the remaining 40% of the estimate being calculated using the cost per foot parametric model described above.

Table 7 summarizes this information arriving at a more realistic point estimate for the initial DDG/A to cost approximately $1,506.76 million dollars.

Table 7. Hybrid DDG/A Cost Estimate

	Cost per Foot ($M)	Cost per Ton ($M)	Cost per Mission Rating ($M)	FY15 $M USD/T1 Unit
AOPS (Canada)	**$ 2.32**	$ 0.12	$ 92.72	$ 741.75
Svalbard-Icebreaker/Offshore Vessel (Norway)	**$ 0.26**	$ 0.01	$ 12.39	$ 86.73
Knud Rasmussen-Offshore Class (Denmark)	**$ 0.38**	$ 0.05	$ 16.36	$ 89.97
Iver Huitfeldt-Blue Ocean Arctic Class Frigate (Denmark)	**$ 0.78**	$ 0.05	$ 50.41	$ 352.87
Fridtjof Nansen-Frigate (Norway)	**$ 1.75**	$ 0.15	$ 139.97	$ 769.86
Mean	**$ 1.10**	$ 0.08	$ 62.37	
DDG 51 (U.S.)	$ 4.24	$ 0.24	$ 267.78	**$ 2,142.20**
	Length (ft)	**60% Portion (DDG 51)**	**40% Portion (Cost/Ft)**	**FY15 $M USD/T1 Unit**
DDG/A Design (Predicted)	**505**	**$ 1,285.32**	**$ 221.44**	**$ 1,506.76**

Following the construction of the initial DDG/A, Figure 13 displays predicted cost savings realized as a result of learning during the production of additional DDG/As. Learning is reflected in a cost estimation by reduced unit costs as shipyards become more and more familiar with the details of the design (Nussbaum, 2014). While it is uncertain how steep the DDG/A learning curve would be, there will certainly be some level of cost savings as more hulls are built.

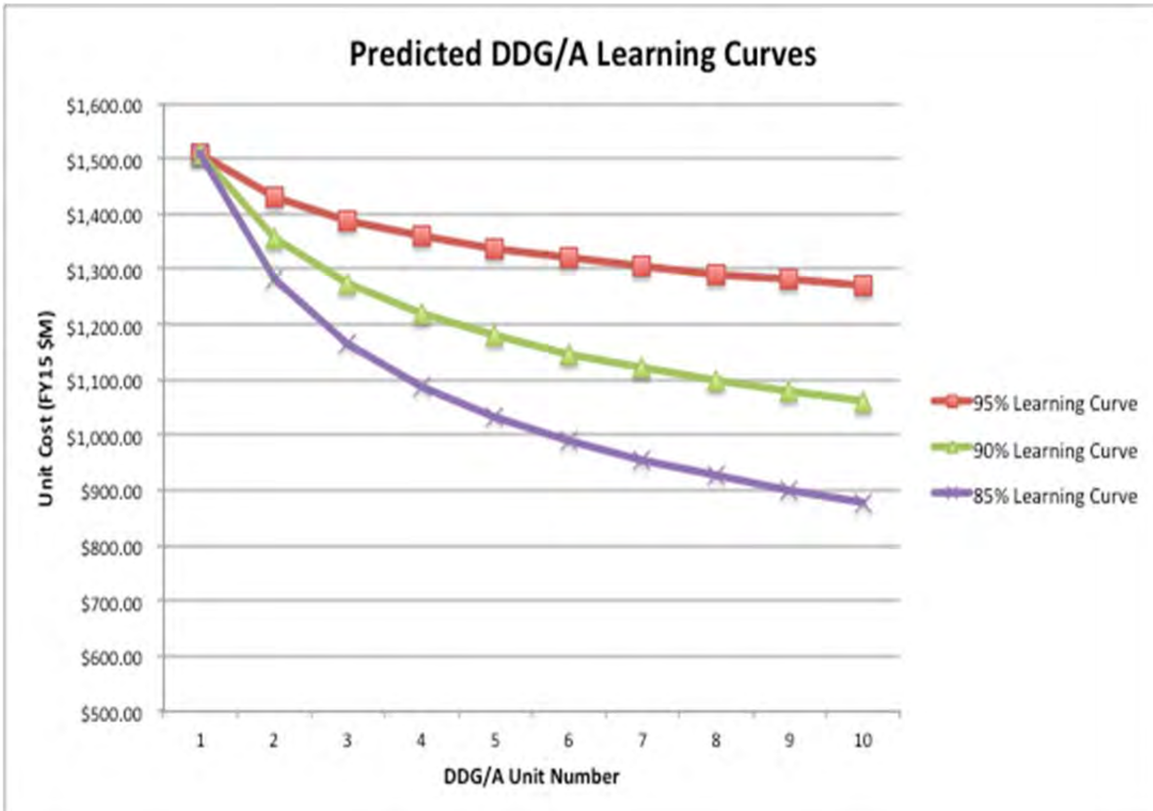

Figure 13. Predicted DDG/A Unit Costs: A Learning Curve Excursion.

In summary, we estimate the likely first unit acquisition cost of a DDG/A to be approximately $1.5 billion, with larger fleets experiencing costs savings following an unknown learning curve trajectory. Table 8 summarizes the predicted total cost ranges for a fleet of three, five or ten DDG/As.

Table 8. DDG/A Fleet Cost Ranges

	3-Ship Fleet	5-Ship Fleet	10-Ship Fleet
Fleet Cost Range (FY15 $M)	$3,953 - $4,328	$6,704 - $7,025	$10,723 - $13,493

3. Sensitivity Analysis

During the sensitivity analysis we explored how significantly the cost of the DDG/A would be affected due to adjustments to its design parameters, specifically: length, tonnage, and mission rating. Summarized in Table 9, each design parameter was reduced by 5% increments followed by recalculating the cost of the initial DDG/A. Developing the DDG/A model further, we see that the DDG/A is most sensitive to changes in tonnage (~8% change in T1 cost due to a 5% change in tonnage), followed by a changes in mission rating (~5% chance in T1 cost due to a 5% change in mission rating).

Table 9. Sensitivity Analysis for DDG/A

	Length	**Tonnage**	**Mission Rating**
Lead DDG/A	**505** $1,506.76 100%	**9750** $1,506.76 100%	**10** $1,506.76 100%
-5% %Δ	$1,495.69 1%	$1,389.38 8%	$1,431.46 5%
-10% %Δ	$1,484.61 1%	$1,316.25 13%	$1,356.12 10%
-15% %Δ	$1,473.54 2%	$1,243.13 17%	$1,280.78 15%
-20% %Δ	$1,462.47 3%	$1,170.00 22%	$1,205.44 20%

4. Risk and Uncertainty Analysis

Naturally there are numerous uncertainties when performing a cost estimation of this level ranging from political risks to logistical uncertainties. At this point we view the following as the largest unknowns to the idea of a DDG/A or similar U.S. Arctic platform.

Arctic platforms are certainly not immune to traditional shipbuilding risks, and arguable more susceptible since we have never built an Arctic platform like this for the U.S. Navy. For example, the research and development (R&D) timeline needed prior to

the construction of the first DDG/A was estimated to be approximately three years, but that was based on previous ship classes since no Arctic R&D baseline exists.

Furthermore, cost overruns in the shipbuilding world seem to be commonplace. In the DDG/A's case, this is compounded by a litany of unique Arctic challenges, which experts commonly link to a cost inflation three to five times greater than comparable ships or infrastructure located in warmer conditions (OUSD(P), 2011). The fact that we have been building Arleigh Burke destroyers since the 1980s should translate into a steeper learning curve with associated cost savings, but that assumes the DDG/A is close enough in engineering complexity as the existing design.

Moreover, it is unclear how our shipyards would be able to handle the additional construction demands given the existing shipbuilding plan already in place. Not to mention the added fiscal constraints the U.S. is already experiencing, the likelihood that the U.S. would pay a premium to build an Arctic platform in the near future is highly unlikely.

Lastly, the U.S. may not need an Arctic platform as large, or as capable, as the current Arleigh Burke, and perhaps could operate more successfully with a ship closer in size to the other offshore vessels, approximately 350ft. This could be accomplished by removing vertical launch modules, helicopter hangers, or other equipment. But in doing so the ship could have reduced missile defense capabilities, usable square footage, and/or a lessened strategic sealift capability-a critical logistical necessity in the Arctic. In short, the design of an Arctic platform is certainly up for debate, and the solution will become clearer as we solidify our priorities in the region.

IV. SUMMARY, CONCLUSION AND RECOMMENDATIONS

The following chapter summarizes our assumptions about the future of the Arctic security environment as well as our cost estimate methodology, cost estimate figures, and our recommendations for the U.S. Navy based on our findings.

A. SUMMARY

In the past 30 years ice coverage throughout the Arctic region has seen considerable recession and has shown no scientific signs of slowing in the near future. As polar ice continues to recede in the region, the potential for increased maritime traffic, significant natural resource disputes, and mounting international tension rises exponentially. Conversations about the region are becoming much more common as evidence by U.S. strategic policies and planning priorities highlighted in the National Arctic Policy and Strategy, the Defense Department Arctic Policy and Strategy, and the Department of the Navy’s Arctic Roadmap.

A very plausible, but hypothetical, scenario where Russia seeks to expand military operations and further their political and economic reach in the region by 2025 substantiates the need for the U.S. to protect its interests and strive to maintain a cooperative Arctic region. Additionally, China developing a stronger Arctic partnership with Russia could add to U.S. motivation to seek future investments to protect national interests in the region and defend its homeland.

With only two operating USCG icebreakers and no patrols vessel or surface combatants, the U.S. faces significant capability gaps in its ability to meet growing concerns in the region. With these capability gaps in mind, this project set out to determine a reasonable per unit cost for a viable surface platform to meet the concerns highlighted in the aforementioned Arctic policy and strategic guidance. Our focus was on possible mission-sets the Surface Navy could get tasked with to include missile defense and early warning, deployment of sea and air systems for strategic sealift for HADR, and maritime security operations.

We conducted a cost estimate for an Arctic-capable platform based upon the U.S.'s political and strategic priorities, the regions current geopolitical situation, and a possible future Arctic region environment. Our cost estimate exploited a hybrid approach incorporating a parametric analysis on like foreign Arctic-capable surface vessels and an analogous comparison to the Arleigh Burke-class destroyer. This cost estimate yielded a point estimate for a possible Arctic-capable platform in which the U.S. could invest to meet the future needs in the Arctic region. The T1 unit cost of the first DDG/A was estimated at $1.507 billion. We then incorporated specific learning curve trajectories which highlight possible future procurement costs savings for multiple-ship fleets of three, five, or ten ships. Additionally, we conducted sensitivity analyses to highlight possible changes in total costs as platform design parameters are adjusted. This analysis concluded that changes in the platforms tonnage would be the most sensitive to overall costs compared to changes in length and mission rating.

B. CONCLUSION

Based on our hybrid parametric and analogy cost estimate approach, we concluded that cost savings could be realized utilizing the DDG/A concept design based on the current Arleigh Burke-class destroyer. Our analysis concluded that the first DDG/A would cost approximately $1.507 billion compared to the current Arleigh Burke destroyer costing approximately $1.8 billion/unit. With the admission that the U.S. may not need an Arctic-capable ship as robust as the DDG/A concept, various Arctic surface platform costs may be derived using this model as engineering details solidify.

Utilizing learning curve analysis, our model concluded a three-ship DDG/A fleet would cost, in FY15 dollars, between $3.95 and $4.33 billion; a five-ship fleet would cost between $6.70 and $7.03 billion; and a ten-ship fleet would cost between $10.72 and $13.49 billion.

C. RECOMMENDATIONS

First, it is our recommendation that the U.S. continues to solidify key Arctic national priorities. In lockstep with this process, the recognition of a potential need for a surface vessel, like the DDG/A, at some point in the future should be given serious

consideration. Given the long lead-time for shipbuilding, policymakers will need to act soon if they want an Arctic-capable surface combatant force in the near future. With the projected environmental and geopolitical timeline, we recommend that the U.S. start building the DDG/A-class, or similar Arctic-capable surface vessels, as soon as fiscally possible. Realistically, the U.S. should pair an Arctic-capable surface vessel with a more robust air, sub-surface, and unconventional warfare capability in the future to make the U.S. a more prepared Arctic nation.

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V. FUTURE RESEARCH

The following represent various topics that relate to the U.S. Navy's surface forces operating in the Arctic. Just as unpredictable as the Arctic environment, the future holds unknown challenges and breakthroughs beyond the scope of this project.

A. ARCTIC CAPABILITY GAPS—SYSTEMS

Communicating in the Arctic represents a significant challenge to operations considering satellite locations being below the horizon in some cases as well as the harsh weather conditions (OUSD(P), 2011). The predominant numbers of communication satellites cover regions around the equator, with only a few in "Polar Orbits." Existing systems such as Iridium satellite phone communications or Lockheed's latest Mobile User Objective System (MUOS) satellites may solve Arctic communication problems, but these systems only solve a portion of the communication problem (Lockheed Martin, 2014).

Additionally, what is the most appropriate composition of assets to counter a subsurface threat in the Arctic? Should the DDG/A be outfitted with a towed-array SONAR operating in conjunction with organic helicopter assets performing undersea missions, or should these mission be conducted predominately by subsurface assets? With potentially limited mobility of a surface vessel in an ice-laden environment, it is reasonable to assess that a surface vessel would not add much to a subsurface mission beyond providing helicopter support.

B. OPPORTUNITY COST ANALYSIS

With the U.S. Navy potentially investing anywhere from \$3.9- \$13.5 billion into the DDG/A program for a fleet of 3-10 ships, the question remains of whether or not the U.S. would be better protected with a different set of Arctic capabilities entirely. For instance, should the U.S. divide that amount of money among Special Operation Forces (SOF) to plus up their Arctic training and equipage?

As with nearly every mission-set, there are several options to counter a threat or vulnerability, and when dealing with the Arctic environment it is entirely plausible that the costs associated with operating surface assets are unrealistic given the challenges and vulnerabilities of sailing through ice-laden waters. In other words, perhaps Arctic air support coupled with one or two SOF teams could complete the desired mission without any surface assets. Managing mission risk by allocating the proper amount of resources to the problem has always been a challenge for DOD and the Arctic is no different.

C. ARCTIC - COAST GUARD VS. NAVY

Based on the geopolitical projections in the Arctic, does the U.S. want to focus on humanitarian missions such as disaster relief and SAR in the Arctic, or does it also want to prepare itself for the potential of military engagements? While the USCG is operationally stretched thin in the Arctic right now, with an appropriate investment to bolster its Arctic fleet, the USCG is very capable of conducting humanitarian missions. The U.S. Navy is also capable of completing similar missions, but the United States runs the risk of militarizing the Arctic if U.S. Navy assets are utilized.

From a cost-benefit aspect, the argument could be made that the USCG and U.S. Navy could mutually benefit from a joint acquisition shipbuilding project. For example, the procurement of an Arctic offshore platform that is nearly identical in hull design, yet slightly tailored to accommodate service specific desires between the USCG and the U.S. Navy—surely lessons learned from the Joint Strike Fighter acquisition program could be incorporated.

D. ARCTIC BASING AND DEEP WATER PORT LOCATIONS

As alluded to previously, a significant challenge for surface ships operating in the Arctic is the lack of sufficient ports, specifically deep-water ports, in the region. Where should the U.S. locate its Arctic Fleet and when should these port facilities be built corresponding with the growing Arctic focus? An additional consideration could be the U.S. Navy joint basing with the USCG, or Canada, in mutually beneficial Arctic areas.

E. WHEN DO WE START BUILDING?

When a nation builds a class of ships it projects to the world its maritime priorities in a material way. Naturally shipbuilding takes a significant amount of time and planning to execute, but the timing decision of when to start welding steel together should not be taken lightly. In DOD's Arctic strategy, the SECDEF expresses similar concerns by saying that if the U.S. begins to build Arctic combatants too soon it risks sparking an international "Arctic arms race" which could potentially militarize the Arctic unintentionally (DOD, 2013a). On the contrary, the U.S. could put itself in a vulnerable position by failing to act promptly while other countries place a higher priority on Arctic security.

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APPENDIX A. POLAR CLASSIFICATIONS

There are various commercial institutions and organizations from different nations that adhere to multiple ways of classifying the extent and thickness of ice in the Arctic. These classifications were set forth to determine the structural requirements for vessels operating in multiple conditions and categories of Arctic ice. There currently is no one doctrinally accepted classification baseline. Ice classification rule sets can differ drastically in each society (see Figure 12) (Tomaszek, 2014).

Rule System	Notation	Class Description	Ice Thickness
Finnish-Swedish Ice Class Rules 2002	IA Super	Escorted operation in all Baltic ice conditions	1.0 m
	IA	Escorted operation medium (smaller vessels) and severe Baltic ice conditions	0.8 m
	IB	Escorted operation in medium ice conditions	0.6 m
	IC	Escorted operation in light ice conditions	0.4 m
American Bureau of Shipping 2002 Pt. 6, Ch.1, Sec. 1	A1	Independent summer operation in Arctic	1.0
	A0	Independently in FY ice	0.6
	B0	Independently in FY ice	0.3 m
	C0	Independently in FY ice	0.3 m (C 6/10)
Arctic Shipping Pollution Prevention Regulations 1995	CAC3	Independent Arctic operation	
	CAC4	Arctic operation	
Det Norske Veritas 2001 Pt. 5, Ch. 1, Sec. 4	ICE-05	Arctic navigation with no ramming	0.5 m
	ICE-10	Arctic navigation with no ramming	1.0 m
	POLAR-10	Arctic navigation with accidental ramming with speed 2.0 m/s	1.0 m
Germanischer Lloyd 2002 Pt. 1, Sec. 15-D	Arc 1	Navigation in first year ice	1.0 m
	Arc 2	Navigation in multi-year ice	1.5 m
Polar Classes (IACS) 26 April 2001 PS1	PC 6	Summer/Autumn operation in medium FY ice with MY ice inclusions	
	PC 7	Summer/Autumn operation in thin FY ice with MY ice inclusions	
Lloyd's Register of Shipping July 2001 Pt. 5, Ch. 9, Secs. 6-9	1AS	Baltic navigation	1.0 m
	1A	Baltic navigation	0.8 m
	1B	Baltic navigation	0.6 m
	1C	Baltic navigation	0.4 m
	AC1	Arctic and Antarctic navigation	
	AC1,5	Arctic and Antarctic navigation	
USSR Register of Shipping 1986 Pt. II, Ch. 26	ULA	Independent summer/autumn navigation in the Arctic	
	UL	Independent summer/autumn navigation in the Arctic in light ice, year-round in non-Arctic seas	
	L1	Summer in Arctic in broken ice, light ice conditions in non-Arctic seas	
	L2	Broken ice in non-Arctic seas	
	L3	Broken ice in non-Arctic seas	
Russian Maritime Register of Shipping 1999 Pt. II, Ch. 3.10	LU7	Summer SY ice / winter FY ice	3.2 m / 2.0 m
	LU5	Summer medium FY ice / winter FY ice	- / 0.9 m
	LU4	Summer FY ice / winter thin FY ice	1.0 m / -
	LU3	Escorted navigation in FY ice	0.65 m
	LU2	Escorted navigation in FY ice	0.5 m

Figure 14. Comparison of Ice Classes (from Tomaszek, 2014).

It is important to understand that there are multiple schools of thought when referring to ice class in the Arctic as it refers to the structural capability of existing naval ships. However, for the purpose of this project we will use ice classifications in accordance with the International Association of Classification Societies (IACS) described in Figure 13 (IACS, 2007).

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions.
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Figure 15. Polar Class Ratings (from IACS, 2007).

The IACS Unified Requirements for Polar Ships were established as guidance for ships constructed of steel and intended for navigation in ice-infested polar waters. There is a distinction between icebreaker and ice-capable ships. Icebreakers are ships that have a specific operational profile that include undertaking missions as an escort or ice manager in ice-covered waters. Ice-capable ships are also rated in the same polar class notation outlined in Figure 13, but without the specific task of breaking ice as a primary mission set. Ice-capable ships are able to conduct *limited* ice breaking but do so in support of maneuverability to conduct their primary mission/operation(s) (IACS, 2007).

The machinery and hulls of all types of Arctic-capable ships are constructed to comply with the requirements of various ranges of polar classifications listed in Figure 12. These descriptions are intended to guide owners, designers and administrations in

selecting an appropriate PC to match the requirements for the ship with its intended voyage or service (IACS, 2007). The PC notation is used throughout this project to convey the differences between classes with respect to operational capability and strength.

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APPENDIX B. SHIP COST CONVERSION AND NORMALIZATION

Each ship's cost data was first converted into U.S. Dollars using the conversion rate on January 1st, of the respective year the data was provided in. Following this conversion the cost was adjusted to FY15 U.S. Dollars to account for inflation using the inflation conversion calculator published by NCCA. Table 10 summarizes these cost conversions and normalizations.

Table 10. Ship Cost Conversion and Normalization (from Barkel & Story, 2014; Thomas, 2007; Canadian American Strategic Review, 2008; de Larrinaga, 2013; DOD, 2013b; Lok, 2008; & Rider, 2013).

T1 Cost (Data Year)	CAD (M)	Conversion Rate (CAD to USD)	USD (M)	Inflation Conversion	FY15 USD Estimate (M)
A/OPS (2015)	$ 831.09	0.8925	$ 741.75	1	**$ 741.75**
	CAD (M)	**Conversion Rate (CAD to USD)**	**USD (M)**	**Inflation Conversion**	**FY15 USD Estimate (M)**
Svalbard (2001)	$ 100.00	0.6668	$ 66.68	1.3007	**$ 86.73**
	DKK (M)	**Conversion Rate (DKK to USD)**	**USD (M)**	**Inflation Conversion**	**FY15 USD Estimate (M)**
Knud Rasmussen (2003)	$ 507.00	7.0872	$ 71.54	1.2577	**$ 89.97**
	Euro (M)	**Conversion Rate (Euro to USD)**	**USD (M)**	**Inflation Conversion**	**FY15 USD Estimate (M)**
Iver Huitfeldt (2008)*	$ 212.60	1.4603	$310.46	1.1366	**$ 352.87**
	NOK (M)	**Conversion Rate (NOK to USD)**	**USD (M)**	**Inflation Conversion**	**FY15 USD Estimate (M)**
Fridtjof Nansen (2011)	$4,172.49	0.1717	$ 716.42	1.0746	**$ 769.86**

*Price w/o Weapons

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APPENDIX C. COST REGRESSION MODELS

The following models detail the regressions completed on the three Offshore Ice-capable ships (Regressions 1-3), as well as all six ships in the dataset (Regressions 3-6) utilizing 95% confidence interval T1 prices. A summarization of F-stats, R-Squares, and P-Levels are aggregated in Table 11.

Table 11. Regression Detail Summary

Offshore Ice Capable Ships (AOPS, Svalbard, Knud Rasmussen ONLY)			
	F-stat	R-Square	P-Level
Cost/Feet Regression	0.087722	0.080648	0.816686
Cost/Ton Regression	0.035186	0.033990	0.881955
Cost/Mission Rating Regression	1.514271	0.602270	0.434430
Offshore Ice Capable Ships Including All Other Classes (ALL six ships)			
	F-stat	R-Square	P-Level
Cost/Feet Regression	2.326385	0.367727	0.201888
Cost/Ton Regression	1.874109	0.319046	0.242843
Cost/Mission Rating Regression	0.801667	0.166956	0.421206

A. REGRESSION MODEL 1

Linear Regression (Offshore Ice Capable Ships ONLY)

Regression Statistics	
R	0.28399
R Square	0.08065
Adjusted R Square	-0.8387
Standard Error	1.56737
Total Number Of Cases	3

Cost per Foot ($M) =- 0.7712 + 0.0059 * Length (ft)

ANOVA

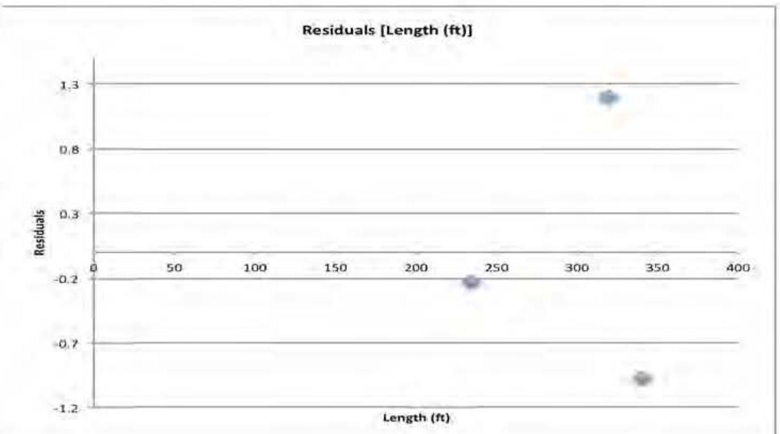
	d.f.	*SS*	*MS*	*F*	*p-level*
Regression	1.	0.2155	0.2155	0.08772	0.81669
Residual	1.	2.45666	2.45666		
Total	2.	2.67217			

	Coefficients	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-level*	*H0 (2%) rejected?*
Intercept	-0.77118	5.9992	-191.66892	190.12656	-0.12855	0.91861	*No*
Length (ft)	0.00589	0.01988	-0.62667	0.63845	0.29618	0.81669	*No*
T (2%)	31.82052						

LCL - Lower value of a reliable interval (LCL)
UCL - Upper value of a reliable interval (UCL)

Residuals

Observation	*Predicted Y*	*Residual*	*Standard Residuals*
1	1.1129	1.2051	1.08734
2	1.23066	-0.97556	-0.88023
3	0.61244	-0.22954	-0.20711



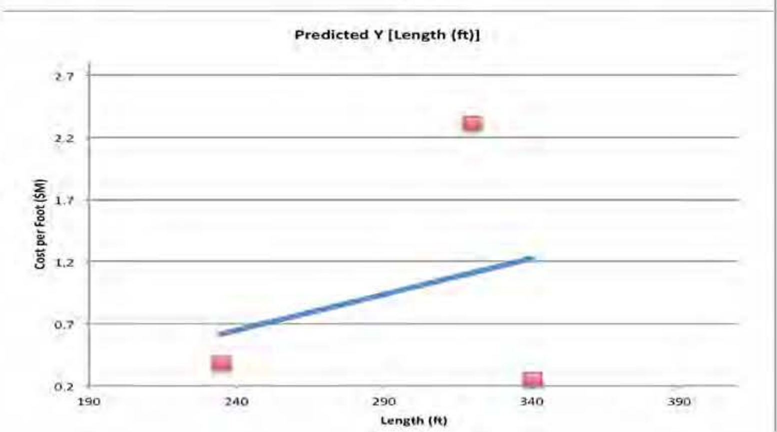


Figure 16. Cost per Foot Regression Details—Offshore Ice-Capable Ships

B. REGRESSION MODEL 2

Linear Regression (Offshore Ice Capable Ships ONLY)

Regression Statistics

R	0.18436
R Square	0.03399
Adjusted R Square	-0.93202
Standard Error	0.07195
Total Number Of Cases	3

Cost per Ton ($M) = 0.0423 + 0.0000 * Tonnage (Approx)

ANOVA

	d.f.	*SS*	*MS*	*F*	*p-level*
Regression	1.	0.00018	0.00018	0.03519	0.88196
Residual	1.	0.00518	0.00518		
Total	2.	0.00536			

	Coefficients	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-level*	*H0 (2%) rejected?*
Intercept	0.04234	0.1024	-3.21601	3.3007	0.41352	0.75038	*No*
Tonnage (Approx)	0.	0.00002	-0.00061	0.00062	0.18758	0.88196	*No*

T (2%) 31.82052

LCL - Lower value of a reliable interval (LCL)

UCL - Upper value of a reliable interval (UCL)

Residuals

Observation	*Predicted Y*	*Residual*	*Standard Residuals*
1	0.06559	0.05031	0.98883
2	0.06523	-0.05143	-1.01081
3	0.04888	0.00112	0.02197

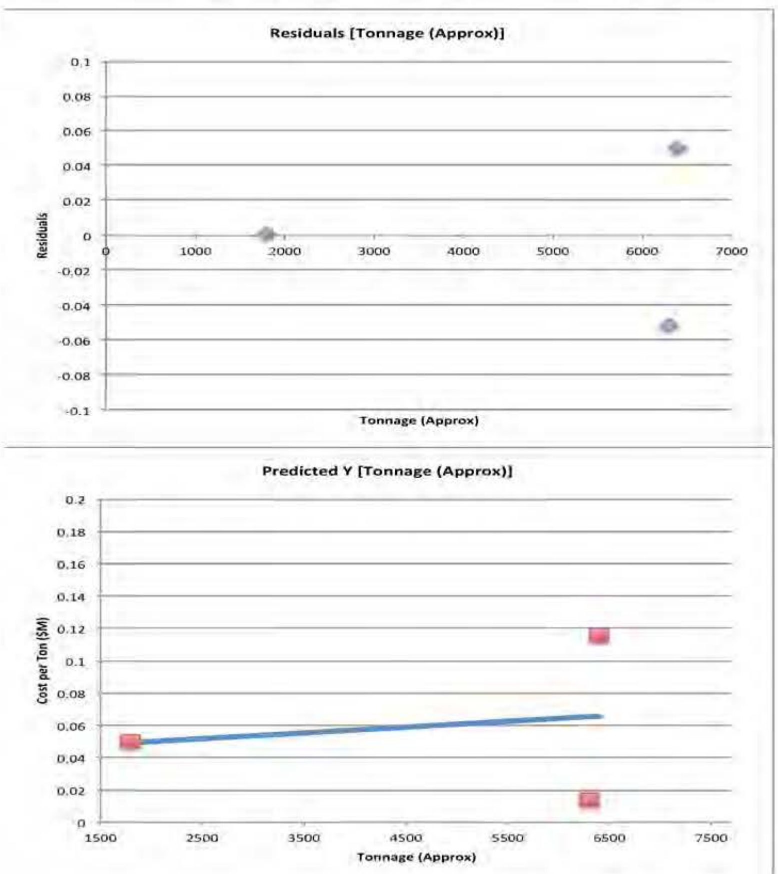


Figure 17. Cost per Ton Regression Details—Offshore Ice-Capable Ships

C. REGRESSION MODEL 3

Linear Regression (Offshore Ice Capable Ships ONLY)

Regression Statistics	
R	0.77606
R Square	0.60227
Adjusted R Square	0.20454
Standard Error	40.38059
Total Number Of Cases	3

Cost per Mission Rating ($M) =- 150.3230 + 27.9237 * "Mission" Rating (1-10)

ANOVA

	d.f.	*SS*	*MS*	*F*	*p-level*
Regression	1.	2,469.15829	2,469.15829	1.51427	0.43443
Residual	1.	1,630.59238	1,630.59238		
Total	2.	4,099.75068			

	Coefficients	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-level*	*H0 (2%) rejected?*
Intercept	-150.32296	156.80439	-5,139.91955	4,839.27363	-0.95867	0.51343	*No*
"Mission" Rating (1-10)	27.92372	22.69193	-694.14536	749.9928	1.23056	0.43443	*No*
T (2%)	31.82052						

LCL - Lower value of a reliable interval (LCL)
UCL - Upper value of a reliable interval (UCL)

Residuals

Observation	*Predicted Y*	*Residual*	*Standard Residuals*
1	73.06681	19.65179	0.68825
2	45.14309	-32.75299	-1.14708
3	3.25751	13.10119	0.45883

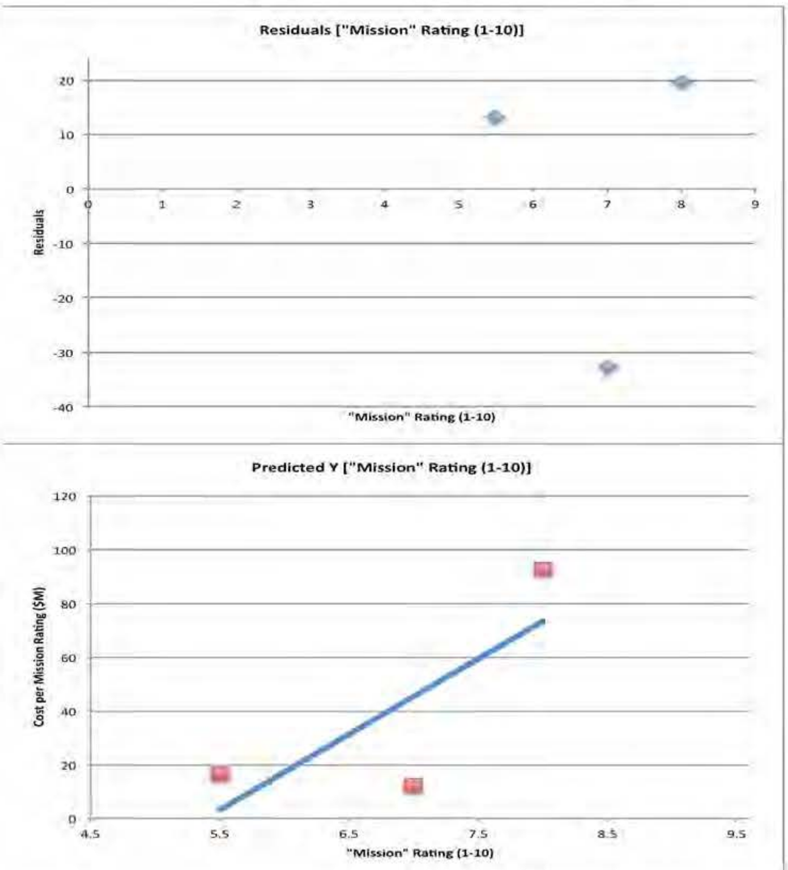


Figure 18. Cost per Mission Rating Regression Details—Offshore Ice-Capable Ships

D. REGRESSION MODEL 4

Linear Regression (All Ships)

Regression Statistics	
R	0.60641
R Square	0.36773
Adjusted R Square	0.20966
Standard Error	1.3474
Total Number Of Cases	6

Cost per Foot ($M) =- 1.8590 + 0.0091 * Length (ft)

ANOVA

	d.f.	*SS*	*MS*	*F*	*p-level*
Regression	1.	4.22352	4.22352	2.32639	0.20189
Residual	4.	7.26194	1.81548		
Total	5.	11.48546			

	Coefficients	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-level*	*H0 (2%) rejected?*
Intercept	-1.85902	2.34668	-10.65193	6.93388	-0.79219	0.47258	*No*
Length (ft)	0.0091	0.00596	-0.01325	0.03144	1.52525	0.20189	*No*
T (2%)	3.74695						

LCL - Lower value of a reliable interval (LCL)

UCL - Upper value of a reliable interval (UCL)

Residuals

Observation	*Predicted Y*	*Residual*	*Standard Residuals*
1	1.05198	1.26602	1.05051
2	1.23392	-0.97882	-0.81219
3	0.27874	0.10416	0.08643
4	2.7349	1.5071	1.25055
5	2.28006	-1.50456	-1.24844
6	2.1436	-0.3939	-0.32685

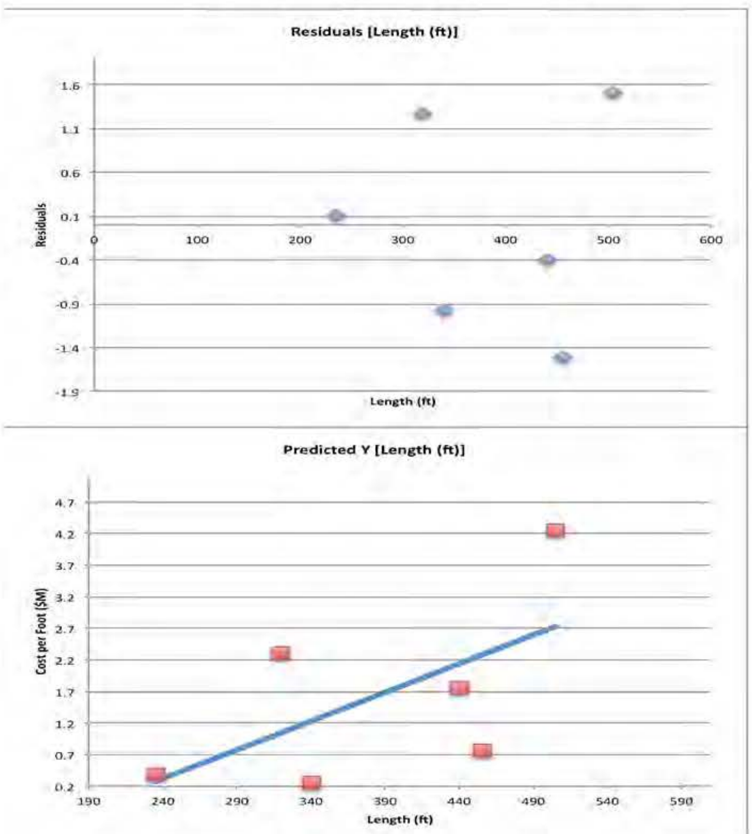


Figure 19. Cost per Foot Regression Details—All Ships

E. REGRESSION MODEL 5

Linear Regression (All Ships)

Regression Statistics

R	0.56484
R Square	0.31905
Adjusted R Square	0.14881
Standard Error	0.07545
Total Number Of Cases	6

Cost per Ton ($M) =- 0.0132 + 0.0000 * Tonnage (Approx)

ANOVA

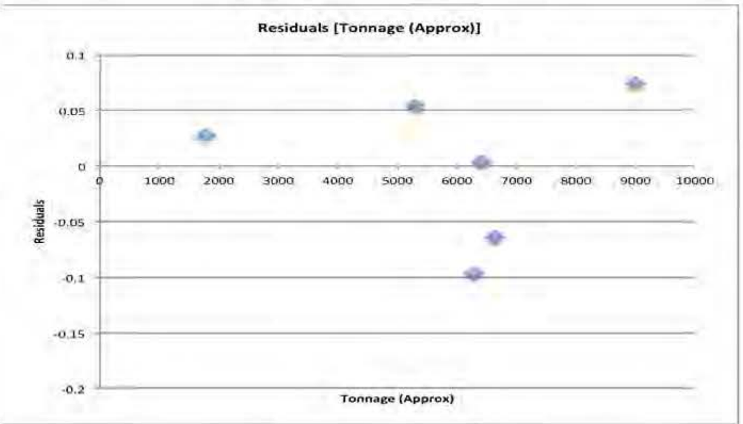
	d.f.	*SS*	*MS*	*F*	*p-level*
Regression	1.	0.01067	0.01067	1.87411	0.24284
Residual	4.	0.02277	0.00569		
Total	5.	0.03344			

	Coefficients	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-level*	*H0 (2%) rejected?*
Intercept	-0.01315	0.09005	-0.35055	0.32425	-0.14607	0.89093	*No*
Tonnage (Approx)	0.00002	0.00001	-0.00003	0.00007	1.36898	0.24284	*No*
T (2%)	3.74695						

LCL - Lower value of a reliable interval (LCL)
UCL - Upper value of a reliable interval (UCL)

Residuals

Observation	*Predicted Y*	*Residual*	*Standard Residuals*
1	0.11234	0.00356	0.05275
2	0.11038	-0.09658	-1.43122
3	0.02214	0.02786	0.41283
4	0.16332	0.07468	1.10665
5	0.11714	-0.06404	-0.94908
6	0.09077	0.05453	0.80806



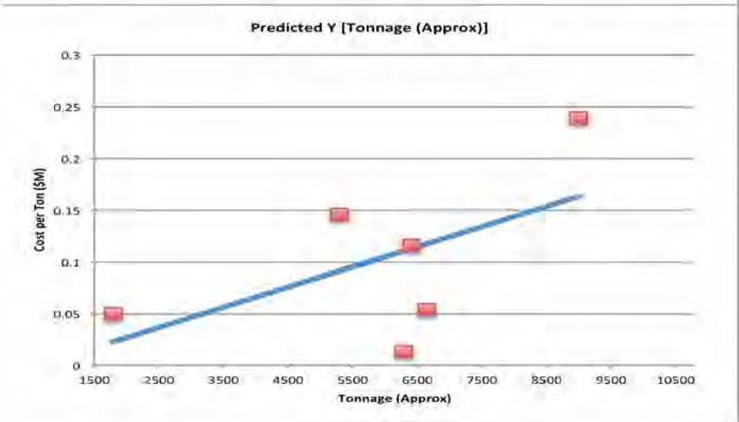


Figure 20. Cost per Ton Regression Details—All Ships

F. REGRESSION MODEL 6

Linear Regression (All Ships)

Regression Statistics

R	0.4086
R Square	0.16696
Adjusted R Square	-0.0413
Standard Error	98.78899
Total Number Of Cases	6

Cost per Mission Rating ($M) =- 143.5672 + 35.1471 * "Mission" Rating (1-10)

ANOVA

	d.f.	*SS*	*MS*	*F*	*p-level*
Regression	1.	7,823.6812	7,823.6812	0.80167	0.42121
Residual	4.	39,037.05465	9,759.26366		
Total	5.	46,860.73585			

	Coefficients	*Standard Error*	*LCL*	*UCL*	*t Stat*	*p-level*	*H0 (2%) rejected?*
Intercept	-143.5672	271.2558	-1,159.94842	872.81403	-0.52927	0.62463	*No*
"Mission" Rating (1-10)	35.14709	39.25476	-111.93844	182.23262	0.89536	0.42121	*No*
T (2%)	3.74695						

LCL - Lower value of a reliable interval (LCL)
UCL - Upper value of a reliable interval (UCL)

Residuals

Observation	*Predicted Y*	*Residual*	*Standard Residuals*
1	137.60954	-44.89094	-0.50805
2	102.46245	-90.07235	-1.01938
3	49.74181	-33.38311	-0.37781
4	137.60954	130.16546	1.47313
5	102.46245	-52.05185	-0.58909
6	49.74181	90.23279	1.0212

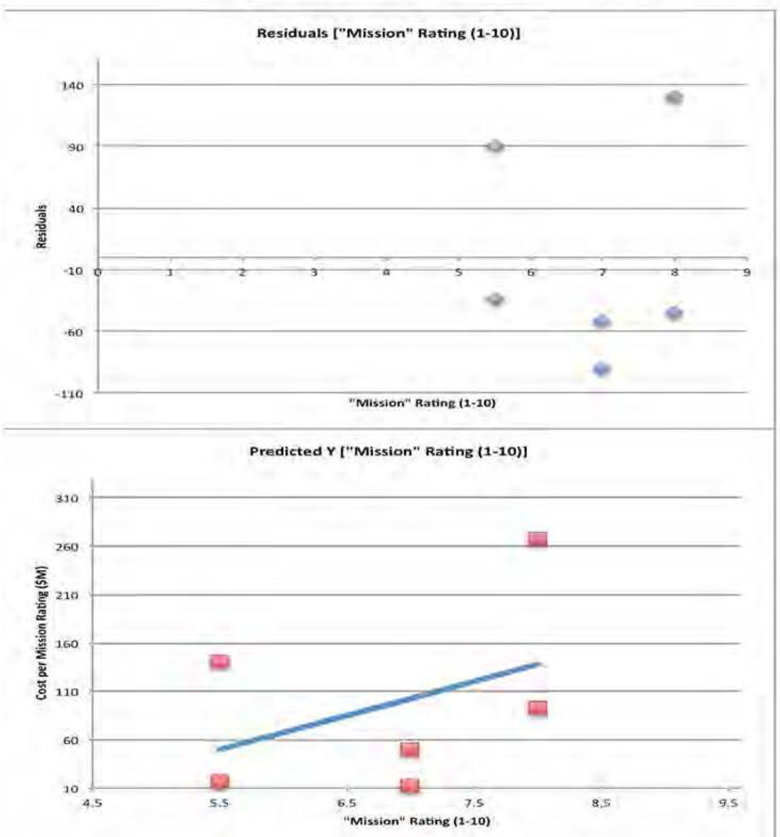


Figure 21. Cost per Mission Rating Regression Details—All Ships

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